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ABSTRACT

This teaching guide was developed to help technical education teachers present courses including robotics to junior and senior high school students. The guide contains six units of instruction. Each unit includes some or all of the following basic components of a unit of instruction: objective sheet, suggested activities for the teacher, answers to assignment sheets, answers to written test, written test, unit evaluation form, teacher supplements, transparency masters, information sheet, assignment sheets, student supplements, and job sheets. Information included only in the teacher's edition includes information on use of the publication, a competency profile, an instructional review and task analysis, a list of related academic and workplace skills, a list of tools, equipment and materials, and a list of eight references. Topics covered in the units are as follows: orientation, nonservo robot operations, servo robot operations, sensors, end-of-arm tooling, and flexible manufacturing. (KC)

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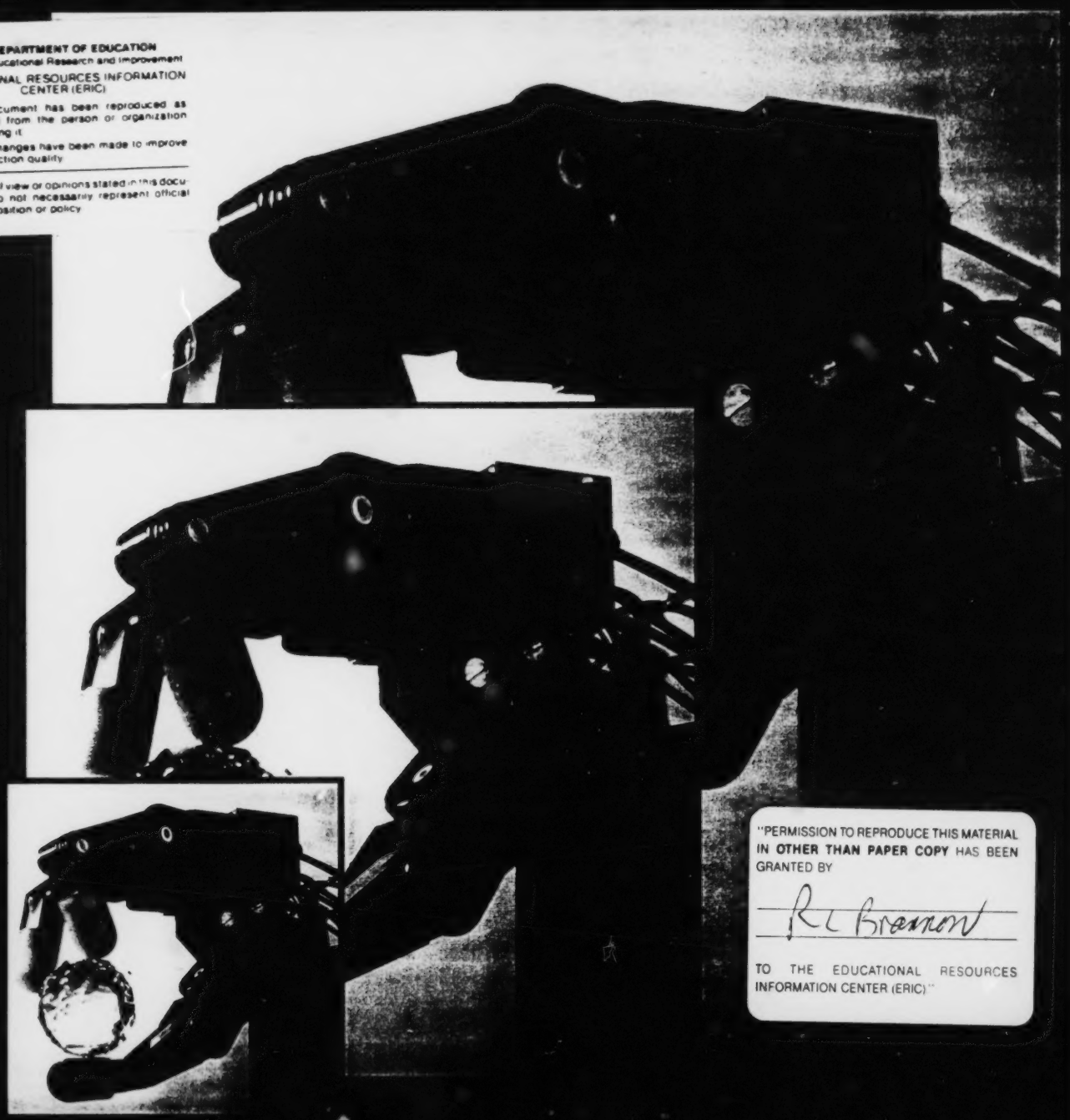

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Introduction to Robotics

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Introduction to Robotics

Teacher Edition

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Foreword

Introduction to Robotics was developed in response to a need for introductory technical training materials for secondary students. This publication will be helpful to students who have completed MAVCC's Exploring Technology Education series in middle/junior high school and are considering entering an automated manufacturing program at the 11th or 12th grade level. Many educational institutions will use *Introduction to Robotics* in their technical education programs at the 9th - 11th grade.

Introduction to Robotics will introduce students to career opportunities in robotics and automated manufacturing. Students will study work cells, flow charting, sequencing, servo and nonservo robot operations, sensors, end-of-arm tooling, and flexible manufacturing. After completing this publication, students should be able to construct a flexible manufacturing system in their robotics lab.

These instructional materials are designed not only for student use but also to assist the teacher in improving instruction. Every effort has been made to make these materials basic, readable, and by all means, usable. Teachers will need to develop instructional strategies for localizing, individualizing, and supplementing the instructional materials.

Special attention should be given to the list of related academic and workplace skills in the introductory pages and to the teaching suggestions in each unit of instruction. These suggestions present academic skills being reinforced by the instructional materials and ways to increase reinforcement of workplace skills. By reinforcing basic skills, the teacher will assist students in improving their employability skills.

As you use these instructional materials, we hope you will find they contribute to the quality of your program. If any problems occur or if you have suggestions for improvement, please call or write us.

Mervin Birdwell, Chairman
Board of Directors
Mid-America Vocational
Curriculum Consortium

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Thanks are also extended to Mary Kellum and Dan Fulkerson, MAVCC Curriculum Specialists, for their assistance with the editing and coordination of this project.

Use of Introductory Materials

Introductory materials are included in the teacher guide only and contain useful information to assist administrators and teachers in planning for instruction.

In addition to the general information such as the table of contents, foreword, and acknowledgements page, information is included on the following:

1. **Use of this publication**—Explains the components of a unit of instruction and how they should be used as part of the teaching/ learning process.

2. **Competency profile**—Provides a record of student performance for each task included in a unit of instruction. This becomes a part of the student's permanent records and should be utilized when directing the student toward employment opportunities.

3. **Instructional/task analysis**—Provides a quick review of contents of the publication; identifies cognitive (knowledge) skills and psychomotor (doing) skills addressed in each unit of instruction.

4. **Related academic and workplace skills list**—Classifies unit tasks (assignment sheets and job sheets) according to related academic and workplace skills being reinforced. Skill areas reflected by skill groups, sub skills, and descriptions have been identified using *Workplace Basics: The Skills Employers Want*, developed by the American Society for Training and Development (ASTD) and the U.S. Department of Labor and adapted by MAVCC.

5. **Tools, equipment, and materials list**—Provides a comprehensive list of those items needed to successfully complete the assignment sheets and/or job sheets; assists administrator/teacher in determining program costs.

6. **Reference list**—Provides a comprehensive list of resources used in the development of this publication.

As you use these materials, it is hoped that they will provide useful information to meet a variety of needs.

Use of This Publication

Instructional units

Introduction to Robotics contains six units of instruction. Each instructional unit in a teacher guide includes some or all of the following basic components of a unit of instruction: objective sheet, suggested activities for the teacher, answers to assignment sheets, answers to written test, written test, unit evaluation form, teacher supplements, transparency masters, information sheet, assignment sheets, student supplements, and job sheets.

All of the unit components focus on measurable and observable learning outcomes. Teachers are encouraged to supplement, personalize, localize, and motivate with these materials in order to develop a complete teaching/learning process.

Units of instruction are designed for use in more than one lesson or class period of instruction. Careful study of each unit of instruction by the teacher will help to determine the following:

- Amount of materials that can be covered in each class period.
- Skills that must be demonstrated.
- Amount of class time needed for demonstrations.
- Amount of time needed for student practice.
- Supplementary materials, including print and nonprint media and equipment and supplies, that must be ordered.
- Resource people who must be contacted.

Objective sheet (Color code: White)

Each unit of instruction is based on performance objectives which state the goals for successful completion of the course. These performance objectives are stated in two forms: unit objectives which state the expected performance of each student after completion of the unit of instruction, and specific objectives which state what the student must do to reach the unit objective.

The objectives should be provided for students and stressed throughout the teaching/learning process. This will help answer any questions concerning performance requirements for each instructional unit. The objectives can also help determine teaching strategies and instructional methods. Teachers should prepare for each unit by deciding how each objective can best be taught.

Teachers should feel free to modify, delete, or add objectives in order to meet the needs of the students and community. When objectives are added, the teacher should remember to supply the needed information, assignment and/or job sheets, and criterion test items.

Suggested activities (Color code: Pink)

This component is included only in the teacher guide. The suggested activities assist teachers during the preparation stage of the teaching/learning process by providing an instructional plan, teaching suggestions, and a list of supplemental resources. Ways to integrate academic and workplace skills have been included in the teacher suggestions, and skill areas have been noted in bold. (A table of academic and workplace skills with accompanying definitions has been provided on page xv.) The teacher should read the suggested activities before teaching the units and decide how each objective can best be taught. Time should also be allowed to obtain supplemental materials, prepare audiovisual materials, and contact outside resources. Duties of the teacher will vary according to the particular unit.

References used in the development of each unit are listed in the suggested-activities section, along with suggested supplemental resources that may be used to teach the unit. These materials can be used by the teacher to supplement her or his knowledge of the subject area or to help students with particular interests or objectives in the area covered.

Instructions for evaluating student performance on the job sheets are also included in the suggested-activities section. Teachers should select and discuss with students the rating scale that will be used.

Assignment and written test answers (Color code: Pink)

Assignment-sheet answers and written-test answers are designed to assist the teacher in evaluation of student performances.

Written test (Color code: Yellow)

This component provides criterion-referenced evaluation of every cognitive objective listed in the unit of instruction. The test appears in the teacher guide only, but duplication is permitted for student use. If objectives have been added, deleted, or modified, appropriate changes should be made on the written test. It is recommended that the tests be divided into shorter tests covering three or four objectives at a time and given soon after those objectives have been covered. A selection of test items from the units covered may be used for final tests at the end of each term if desired.

Unit evaluation form (Color code: White)

This sheet provides teachers with a record of each students performance on a unit of instruction. It includes space for assignment sheet ratings, job sheet ratings, written test scores, and teacher comments. The unit evaluation form is included in the teacher guide only, but may be duplicated.

Use of This Publication

Teacher supplements (Color code: White)

This component is included only in the teacher guide. Teacher supplements are optional materials for the teacher to use. They have three purposes: to provide the teacher with higher level materials to stretch the advanced student, with remedial information or practice to assist the less-advanced student, and with state-of-the-art information in which the teacher may not have background or with information that is not readily available in other books. Some teacher supplements may be duplicated for student use and are marked accordingly.

Transparency masters (Color code: White)

Transparencies are included in the teacher guide only and are used to direct the students' attention to the topic of discussion. They may provide illustrations, charts, schematics, or additional information needed to clarify and reinforce objectives included in the unit of instruction.

Information sheet (Color code: Green)

The information sheet provides the content essential for meeting the cognitive (knowledge) objectives of the unit. Teachers will find that the information sheet serves as an excellent guide for presenting background knowledge necessary to develop the skills specified in the unit objective. Students should read the information sheet before the information is discussed in class. Space is provided in margins for students and teachers to add notes that supplement, localize, personalize, or provide information for the teaching of each objective.

Student supplements (Color code: White)

Student supplements are included in the student manual. The information presented in a student supplement may consist of tables, charts, written information, forms, or other information students will need in order to complete one or more of the assignment and/or job sheets. Students are not directly tested over the information presented in a supplement; however, their ability to apply this information may be evaluated in the completion of assignment sheets or job sheets.

Assignment sheets (Color code: Tan)

Assignment sheets provide students with pencil and paper activities that give students the opportunity to make practical application of the knowledge in the information sheet. Criteria are provided to objectively evaluate student performance.

Job sheets (Color code: Blue)

The job sheets provide criteria to objectively evaluate student performance, a list of required equipment and materials, and a step-by-step procedure for performing a psychomotor skill. The teacher should discuss the equipment and materials available in the classroom and/or laboratory and demonstrate the procedure prior to having students practice procedure. When a student is ready to be evaluated, the teacher should follow instructions for evaluating student performance which may be found in the teacher guide.

Job sheets are an important segment of each unit. Job sheets provide potential employers with a picture of the skills being taught during training and the performances that might reasonably be expected from an individual who has had this training.

Disseminating material

Material may be given out a unit or page at a time to keep the material before the student always new. Some teachers ask students to furnish a three-ring binder or folder for the current unit of study. This is convenient for students taking the material home to study. Upon completion, each unit is then placed in a larger binder. Some teachers prefer to store the material by unit in filing cabinets or boxes until needed.

For best results, provide student materials for each student. Student manuals contain objective sheets, information sheets, student supplements, assignment sheets, and job sheets. Students should be allowed to take their materials home at the end of the course.

Academic and Workplace Skills
(Classifications and Definitions)

Skill Groups	Sub Skills	Definitions
Learning Skills	Learning to learn	Developing ability to apply knowledge to other situations; knowing how to learn.
Foundation Skills	Reading	Comprehending written information and analyzing, summarizing, and applying what has been read to a specific task.
	Writing	Communicating a thought, idea or fact in written form in a clear, concise manner.
	Math	Applying computation skills such as reasoning, estimation, and problem solving as they are actually used on the job.
	Science	Applying knowledge learned through study or practice that is based on scientific principles as they relate to specific tasks.
Communication Skills	Listening	Listening for content, conversation, long-term contexts, emotional meaning, and directions.
	Oral communication	Communicating a thought, idea, or fact in spoken form in a clear, concise manner.
Adaptability Skills	Creative thinking	Using imagination to create something new—i.e. an idea, invention, work of art.
	Problem solving (critical thinking)	Recognizing and defining problems, inventing, and implementing solutions, and tracking and evaluating results.
Personal Management Skills	Self-esteem	Developing self-confidence and creating a positive self-image.
	Motivation/goal setting	Setting and meeting defined goals and objectives.
	Personal and career development	Emphasizing self-direction by establishing and implementing a plan.
Group Effectiveness Skills	Interpersonal relations	Developing ability to maintain positive relations with others.
	Negotiation	Resolving conflict between two or more individuals.
	Teamwork	Working together in a group to reach a common goal.
Influence Skills	Organizational effectiveness	Adapting to the organization's goals, values, culture, and traditional modes of operation.
	Leadership	Directing/influencing group in performance of a specific task; accepting responsibility for others.

Introduction to Robotics

Competency Profile

Name: _____

Directions: Evaluate the student using the rating scale below. Write the appropriate number to indicate the degree of competency achieved. The descriptions associated with each of the numbers focused on a level of student performance for each of the tasks listed. The written test scoreline is provided for optional teacher use. It may not be applicable in all cases.

Option A

Rating scale:
- 4 - Skilled - Can perform job with no additional training.
- 3 - Moderately Skilled - Has performed job during training program; limited additional training may be required.
- 2 - Limited Skill - Has performed job during training program; additional training is required to develop skill.
- 1 - Unskilled - Is familiar with process, but is unable to perform job.
- 0 - No Exposure - No information or practice provided during training program, complete training required.
- NA - Non-applicable.

Option B

Yes - Can perform with no additional training
No - Is unable to perform satisfactorily

Unit 1: Orientation

_____1. Draw work envelopes.
_____2. Draw a work cell and locate all safety devices.
_____3. Survey local industries for robotics use.
_____4. Survey a career in robotics.
_____5. _____

_____Written Test Score

Unit 2: Nonservo Robot Operations

_____1. Calculate the lift capabilities of the Mercury robot.
_____2. Develop a flowchart for a sequence of operations.
_____3. Draw the work envelope for the Mercury robot.
_____4. Locate axes and degrees of freedom for the Mercury robot.
_____5. Identify limit switches, solenoid locations, and addresses for the Mercury robot.
_____6. Enter a program using event sequencing.
_____7. Enter a program to operate the Mercury robot using output reenergization.
_____8. Develop a flowchart and program for a robotic work cell application.
_____9. _____

_____Written Test Score

Unit 3: Servo Robot Operations

_____1. Determine critical specifications using a robot manufacturer's specification sheet.
_____2. Determine meanings of various commands using the *ACL Reference Guide*.
_____3. Define various commands using the *ACL Reference Guide*.
_____4. Explain the sequence of operation of a given program using the *ACL Reference Guide*.
_____5. Design a flowchart for a robotic application.
_____6. Move and teach a robot using the teach pendant.
_____7. Develop a flowchart and program for a robotic work cell application.
_____8. _____

_____Written Test Score

Unit 4: Sensors

_____1. Choose the proper sensors for robotic applications using sensor manufacturers catalogs.
_____2. Develop a flowchart and program for a robotic work cell application using a "part in place" sensor.
_____3. Develop a flowchart and program for a robotic application performing an inspection.
_____4. Develop a flowchart and program for a complete robotic work cell.
_____5. Develop a flowchart and program for a servo robotic work cell application using a "part in place" sensor.
_____6. Develop a flowchart and program for a robotic application performing a measuring/sorting operation.
_____7. _____

_____Written Test Score

Unit 5: End-of-Arm Tooling

_____1. Choose end-of-arm tooling for various robotic applications.
_____2. Develop a flowchart and program for a robotic work cell application using a vacuum gripper.
_____3. Develop a flowchart and program for a robotic work cell application using a sealant dispenser.
_____4. Develop a flowchart and a program for a robotic spray painting application.
_____5. _____

_____Written Test Score

Unit 6: Flexible Manufacturing

_____1. Study the feasibility of creating a flexible manufacturing system to produce a product in your robotics lab.
_____2. Construct a flexible manufacturing system in your robotics lab.
_____3. _____

_____Written Test Score

COMMENTS: _____

_____

_____

_____

_____

Evaluator: _____ Date: _____

* Permission to duplicate this profile is granted.

Introduction to Robotics

Instructional/Task Analysis

Related Information: What the Student Should Know	Application: What the Student Should Be Able to Do
Unit 1: Orientation	
1. Terms and definitions	14. Draw work envelopes
2. History of robotics	15. Draw a work cell and locate all safety devices
3. Introduction of computers	16. Survey local industries for robotics use
4. Basic elements of a robotic system	17. Survey a career in robotics
5. Applications of robots	
6. Reprogrammable and multifunctional robots	
7. Parts of a work envelope	
8. Basic types of work envelopes	
9. Causes of unexpected robot movement	
10. Injuries possible with unexpected robot movement	
11. Hazards related to using end-of-arm tooling	
12. Protective safety devices for robotic systems	
13. Careers in the robotics industry	

Related Information: What the Student Should Know	Application: What the Student Should Be Able to Do
Unit 2: Nonservo Robot Operations	
1. Terms and definitions	18. Calculate the lift capabilities of the Mercury robot
2. Classifications of robots according to their motion control	19. Develop a flowchart for a sequence of operations
3. Basic types of robot arm geometry	20. Draw the work envelope for the Mercury robot
4. Orientation axes of wrist rotation	21. Locate axes and degrees of freedom for the Mercury robot
5. Characteristics of fluid power sources for nonservo robots	22. Identify limit switches, solenoid locations, and addresses for the Mercury robot
6. Characteristics of hydraulic drive systems	23. Enter a program using event sequencing
7. Characteristics of pneumatic drive systems	24. Enter a program to operate the Mercury robot using output reenergization
8. On-line and off-line programming	25. Develop a flowchart and program for a robotic work cell application
9. Basic robot programming	
10. Event sequence programming	
11. Sequence of events used in determining the home position for the robot	
12. Basic flowchart symbols	
13. Basic principles of robotic flowcharting	
14. PLC components	
15. Characteristics of PLC programming of nonservo robots	
16. Terms and definitions related to PLC programming	
17. Verification and identification of input and output addresses	

Related Information: What the Student Should Know	Application: What the Student Should Be Able to Do
Unit 3: Servo Robot Operations	
1. Terms and definitions	16. Determine critical specifications using a robot manufacturer's specification sheet
2. Types of robotic controllers according to their technology level	17. Determine meanings of various commands using the *ACL Reference Guide*
3. Robotic controllers	18. Define various commands using the *ACL Reference Guide*
4. Path characteristics of robot motion control	19. Explain the sequence of operation of a given program using the *ACL Reference Guide*
5. Types of axis control when teaching a robot	20. Design a flowchart for a robotic application
6. Types of loop control	21. Move and teach a robot using the teach pendant
7. Characteristics of open and closed loop control systems	22. Develop a flowchart and program for a robotic work cell application
8. Advantages of feedback on robotic operations	
9. Components of servo system control	
10. Stepper motor control	
11. Major components of a teach pendant	
12. Components of a teach pendant and their functions	
13. Critical specifications of a robotic system	
14. Servo controlled robots	
15. Applications for closed loop control and open loop control	

Related Information: What the Student Should Know	Application: What the Student Should Be Able to Do
Unit 4: Sensors	
1. Terms and definitions	9. Choose the proper sensors for robotic applications using sensor manufacturers' catalogs
2. Purposes of sensors in robot operations	10. Develop a flowchart and program for a robotic work cell application using a "part in place" sensor
3. Basic categories of sensors	11. Develop a flowchart and program for a robotic application performing an inspection
4. Contact sensors	12. Develop a flowchart and program for a complete robotic work cell
5. Noncontact sensors	13. Develop a flowchart and program for a servo robotic work cell application using a "part in place" sensor
6. Process control sensors	14. Develop a flowchart and program for a robotic application performing a measuring/sorting operation
7. Sensor operations within the work cell	
8. Sensor programming	
Unit 5: End-of-Arm Tooling	
1. Terms and definitions	
2. Basic categories of end-of-arm tooling	
3. General requirements for end-of-arm tooling	
4. Power sources used in end-of-arm, tooling	
5. Characteristics of grippers	
6. Characteristics of vacuum devices	
7. Characteristics of magnetic devices	
8. Flexible pneumatic devices	
9. Special purpose tools and special purpose devices	

Related Information: What the Student Should Know	Application: What the Student Should Be Able to Do
10. Tool center point	12. Choose end-of-arm tooling for various robotic applications
11. Program control for end-of-arm tooling	13. Develop a flowchart and program for a robotic work cell application using a vacuum gripper
	14. Develop a flowchart and program for a robotic work cell application using a sealant dispenser
	15. Develop a flowchart and a program for a robotic spray painting application

Unit 6: Flexible Manufacturing

1. Terms and definitions	12. Study the feasibility of creating a flexible manufacturing system to produce a product in your robotics lab
2. Abbreviations related to flexible manufacturing	13. Construct a flexible manufacturing system in your robotics lab
3. Types of manufacturing	
4. Basic types of manufacturing plant layouts	
5. Basic principles of flexible manufacturing	
6. Principles of computer-integrated manufacturing	
7. Productivity	
8. Cost of quality	
9. Management by objectives	
10. Just-in-time	
11. Material handling	

Related Academic and Workplace Skills For *Introduction to Robotics*

Task	Skill Group	Sub Skill	Description
Unit 1: Orientation			
Draw work envelopes. (A.S. 1)	Foundation Skills	Reading	Applies technical words and information derived from printed materials; interprets charts and drawings to obtain information; applies information to new situation
		Math	Constructs geometric figures to scale; follows dimensions specified in part A; determines dimensions for part B
	Adaptability Skills	Creative Thinking	Creates new design for part B
Draw a work cell and locate all safety devices. (A.S. 2)	Foundation Skills	Reading	Applies information and concepts derived from printed materials; applies information to new situation; follows written directions
		Math	Draws area to scale on grid paper
	Adaptability Skills	Creative Thinking	Creates new design
	Influence Skills	Organizational Effectiveness	Identifies characteristics desired by organization/ industry—safety for employees
Survey local industries for robotics use. (A.S. 3)	Foundation Skills	Reading	Determines what information is needed; follows written directions
		Writing	Takes notes during surveys; records data; organizes information into an appropriate format; completes forms accurately
	Communications Skills	Oral Communication	Asks questions to obtain information; speaks in a clear, concise manner; presents findings to class
		Listening	Listens for content
	Personal Management Skills	Personal and Career Development	Explores career opportunities

Task	Skill Group	Sub Skill	Description
Survey a career in robotics. (A.S. 4)	Foundation Skills	Reading	Determines what information is needed; follows written directions; uses written resources to obtain information
		Writing	Takes notes from various sources; records data from research; organizes information into an appropriate format; completes form accurately
	Communication Skills	Oral Communication	Asks questions to obtain information; speaks in a clear, concise manner; presents findings to class
		Listening	Listens for content
	Personal Management Skills	Personal and Career Development	Explores career opportunities; identifies education, training, and other requirements needed for career in robotics
Unit 2: Nonservo Robot Operations			
Calculate the lift capabilities of the Mercury robot. (A.S. 1)	Foundation Skills	Reading	Analyzes and applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information; uses student supplement to obtain information
		Math	Applies computation skills (addition, subtraction, multiplication, and division) as they are actually used on the job; shows mathematical calculation work; applies formulas
		Science	Demonstrates understanding of Pascal's Law
	Adaptability Skills	Problem Solving	Draws conclusions based on data and calculation; demonstrates logical reasoning in reaching a conclusion
Develop a flowchart for a sequence of operations. (A.S. 2)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into an appropriate format (flowchart)
	Adaptability Skills	Creative Thinking	Creates a new design (flowchart)
		Problem Solving	Evaluates scenario and gives logical solution

Task	Skill Group	Sub Skill	Description
Draw the work envelope of the Mercury robot. (A.S. 3)	Foundation Skills	Reading	Applies technical words and information derived from printed materials; interprets data to obtain information; applies information to new situation
		Math	Constructs geometric figures to scale; follows dimensions specified
	Adaptability Skills	Creative Thinking	Creates new design
Locate axes and degrees of freedom of the Mercury robot. (A.S. 4)	Foundation Skills	Reading	Analyzes and applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawing to obtain information
	Adaptability Skills	Problem Solving	Evaluates conditions and gives logical solution
Identify limit switches, solenoid locations, and addresses for the Mercury robot. (J.S. 1)	Foundation Skills	Reading	Analyzes and applies what has been read to specific job-related task; understands technical words; interprets drawings to obtain information; draws conclusions
		Writing	Records data on given illustrations in appropriate locations
	Adaptability Skills	Problem Solving	Demonstrates logical reasoning in reaching a conclusion
Enter a program using event sequencing. (J.S. 2)	Foundation Skills	Reading	Analyzes and applies what has been read to specific job-related task; understands technical words; interprets drawings to obtain information; draws conclusions
	Adaptability Skills	Problem Solving	Demonstrates logical reasoning in reaching a conclusion; evaluates solution (computer program) for errors (bugs)
Enter a program to operate the Mercury robot using output reenergization. (J.S. 3)	Foundation Skills	Reading	Analyzes and applies what has been read to specific job-related task; understands technical words; interprets drawing to obtain information; draws conclusions
	Adaptability Skills	Problem Solving	Demonstrates logical reasoning in reaching a conclusion; evaluates solution (computer program) for errors (bugs)

Task	Skill Group	Sub Skill	Description
Develop a flowchart and program for a robotic work cell application. (J.S. 4)	Foundation Skills	Reading	Analyzes job-related scenarios; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenarios and gives logical solution; evaluates solution (computer program) for errors (bugs)
Unit 3: Servo Robot Operations			
Determine critical specifications using a robot manufacturer's specification sheet. (A.S. 1)	Foundation Skills	Reading	Analyzes and applies what has been read to specific task; understands technical words; determines what information is needed; uses standard occupational resource material (manufacturer's spec sheet) to obtain information
		Writing	Presents answers in a clear and understandable form; uses technical words; records data from spec sheet
Determine meanings of various commands using the *ACL Reference Guide*. (A.S. 2)	Foundation Skills	Reading	Understands technical words; determines what information is needed; uses standard occupational resource material (*ACL Reference Guide*) to obtain information
		Writing	Records data from *ACL Reference Guide*
Define various commands using the *ACL Reference Guide*. (A.S. 3)	Foundation Skills	Reading	Understands technical words; determines what information is needed; uses standard occupational resource material (*ACL Reference Guide*) to obtain information
		Writing	Presents answers in a clear and understandable form; uses technical words; records data from *ACL Reference Guide*

Task	Skill Group	Sub Skill	Description
Explain the sequence of operation of a given program using the *ACL Reference Guide*. (A.S. 4)	Foundation Skills	Reading	Understands technical words; determines what information is needed; uses standard occupational resource material (*ACL Reference Guide*) to obtain information
		Writing	Records data from *ACL Reference Guide*; writes logical and understandable sentences; organizes sentences to show correct sequence of operation of program; uses technical words
	Adaptability Skills	Problem Solving	Demonstrates logical reasoning in reaching a conclusion
Design a flowchart for a robotic application. (A.S. 5)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into an appropriate format (flowchart)
	Adaptability Skills	Creative Thinking	Creates new design (flowchart)
		Problem Solving	Evaluates scenario and gives logical solution
Move and teach a robot using the teach pendant. (J.S. 1)	Foundation Skills	Reading	Analyzes and applies what has been read to specific tasks; understands technical words; follows written directions; uses standard occupational resource material (user manual) to obtain information
Develop a flowchart and program for a robotic work cell application. (J.S. 2)	Foundation Skills	Reading	Analyzes job-related scenarios; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenarios and gives logical solution; evaluates solution (computer program) for errors (bugs)

Task	Skill Group	Sub Skill	Description
Unit 4: Sensors			
Choose the proper sensors for robotic applications using sensor manufacturers' catalogs. (A.S. 1)	Foundation Skills	Reading	Analyzes job-related scenarios; applies what has been read to specific task; understands technical words; determines what information is needed; uses standard occupational resource materials (manufacturers' catalogs) to obtain information
		Writing	Records data from manufacturers' catalogs; writes logical and understandable sentences; uses technical words
	Adaptability Skills	Problem Solving	Evaluates scenarios and gives logical solutions
Develop a flowchart and program for a robotic work cell application using a "part in place" sensor. (J.S. 1)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenario and gives logical solution; evaluates solution (computer program) for errors (bugs)
Develop a flowchart and program for a robotic application performing an inspection. (J.S. 2)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenario and gives logical solution; evaluates solution (computer program) for errors (bugs)

Task	Skill Group	Sub Skill	Description
Develop a flowchart and program for a complete robotic work cell. (J.S. 3)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenario and gives logical solution; evaluates solution (computer program) for errors (bugs)
Develop a flowchart and program for a servo robotic work cell application using a "part in place" sensor. (J.S. 4)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenario and gives logical solution; evaluates solution (computer program) for errors (bugs)
Develop a flowchart and program for a robotic application performing a measuring/sorting operation. (J.S. 5)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenario and gives logical solution; evaluates solution (computer program) for errors (bugs)

Task	Skill Group	Sub Skill	Description
Unit 5: End-of-Arm Tooling			
Choose end-of-arm tooling for various robotic applications. (A.S. 1)	Foundation Skills	Reading	Analyzes job-related scenarios; applies what has been read to specific task; understands technical words; determines what information is needed
		Writing	Writes logical and understandable sentences; uses technical words
	Adaptability Skills	Problem Solving	Evaluates scenarios and gives logical solutions
Develop a flowchart and program for a robotic work cell application using a vacuum gripper. (J.S. 1)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenario and gives logical solution; evaluates solution (computer program) for errors (bugs)
Develop a flowchart and program for a robotic work cell application using a sealant dispenser. (J.S. 2)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenario and gives logical solution; evaluates solution (computer program) for errors (bugs)

Task	Skill Group	Sub Skill	Description
Develop a flowchart and a program for a robotic spray painting application. (J.S. 3)	Foundation Skills	Reading	Analyzes job-related scenario; applies what has been read to specific task; understands technical words; determines what information is needed; interprets drawings to obtain information
		Writing	Uses technical words and symbols; organizes information into appropriate formats (flowchart and computer program)
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart and computer program)
		Problem Solving	Evaluates scenario and gives logical solution; evaluates solution (computer program) for errors (bugs)
Unit 6: Flexible Manufacturing			
Study the feasibility of creating a flexible manufacturing system to produce a product in your robotics lab. (A.S. 1)	Foundation Skills	Reading	Analyzes and applies what has been read to specific tasks; understands technical words; determines what information is needed; follows written directions
		Writing	Takes notes from various sources (team members); summarizes information; organizes information into a clear, concise presentation
	Communication Skills	Oral Communication	Communicates ideas and facts in spoken form to team; asks questions to obtain and clarify information from team; adapts presentation to audience (class); speaks in a clear, concise manner
		Listening	Listens for content and long-term contexts
	Adaptability Skills	Creative Thinking	Formulates mission statement; identifies objectives of team; develops implementation plan; prepares presentation based on team input; develops visual aids to create audience interest (if needed)
		Problem Solving	Recognizes problems and gives solutions
	Group Effectiveness Skills	Interpersonal Relations	Applies human relation skills to role play situation

Task	Skill Group	Sub Skill	Description
		Negotiation	Assists in reaching a consensus through compromise; resolves conflicts within group as needed
		Teamwork	Recognizes differences between team members; works effectively with others to reach a common goal
	Influence Skills	Organizational Effectiveness	Adapts to the organization's (industry's) mode of operation (teamwork); analyzes importance of mission statements, work objectives, and implementation plans
		Leadership	Assumes responsibility for group; directs individuals in performance of tasks Note: Some students will also demonstrate other leadership skills such as organization and delegation.
Construct a flexible manufacturing system in your robotics lab. (U.S. 1)	Foundation Skills	Reading	Analyzes and applies what has been read to specific tasks; understands technical words; determines what information is needed; follows written directions
		Writing	Takes notes from various sources (team members); summarizes information; uses technical words and symbols; organizes information into appropriate formats (material and equipment list, flowchart, computer program, and maintenance schedule)
	Communication Skills	Oral Communication	Communicates ideas and facts in spoken form to team; asks questions to obtain and clarify information from team
		Listening	Listens for content and long-term contexts
	Adaptability Skills	Creative Thinking	Creates new designs (flowchart, computer program, and lists)
		Problem Solving	Recognizes problems and gives solutions; evaluates solution (computer program) for errors (bugs)

Task	Skill Group	Sub Skill	Description
	Group Effectiveness Skills	Interpersonal Relations	Applies human relation skills to role play situation
		Negotiation	Assists in reaching a consensus through compromise; resolves conflicts within group as needed
		Teamwork	Recognizes differences between team members; works effectively with others to reach a common goal
	Influence Skills	Organizational Effectiveness	Adapts to the organization's (industry's) mode of operation (teamwork)
		Leadership	Assumes responsibility for group; directs individuals in performance of tasks Note: Some students will also demonstrate other leadership skills such as organization and delegation

Tools, Equipment, and Materials List

Note: This publication is not designed to be a "stand alone" curriculum. It will only be effective as part of an existing program that covers the sciences that comprise robotics such as fluid power, electronics, and electromechanics. The tools, equipment, and materials required for an automated manufacturing technology program would be extensive. The following list shows only those items required for the assignment and job sheets in this publication.

Computer software for lead through
Paper, gridded
Personal computer
Pneumatic power supply
Pneumatic spray painting system
Pneumatic syringe dispenser
Programmable logic controller (PLC)—Allen Bradley SLC 100
Programming device (hand-held programmer or personal computer and ladder diagram software)
Reference materials
- (1) *ACL Reference Guide*
- (2) User manuals for Amatrol Mercury robot(s) and Scorbot®-ER V
  Note: Other user manuals are required if the lab has other robots.
- (3) Manufacturer's catalogs for robots, sensors, and end-of-arm tooling

Robots
- (1) Mercury (available from Amatrol, Inc.)
- (2) Scorbot®-ER V (available from Eshed Robotec, Inc.)

Teach pendant and controller for robot in lab
Templates, flowchart symbols
Vacuum gripper
Vacuum pump
Work cell
- (1) With "part in place" sensor
- (2) With part inspection sensor

Note: The scenarios given in many of the assignment and job sheets could be adapted to any robots available, and the work cells could be built in house.

References

Engelberger, Joseph F. *Robotics in Practice*. Great Britain: AMACOM, 1982.

Hoekstra, Robert L. *Robotics and Automated Systems*. Cincinnati, OH: South-Western Publishing Company, 1986.

Malcolm, Douglas R., Jr. *Robotics: An Introduction*. Boston, MA: Breton Publishers, 1985.

Rauh, Bob and Stan Kaltwasser. *Programmable Logic Controllers*. Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1990.

Rehg, James. *Introduction to Robotics*. Barrington, IL: TPC Training Systems/Technical Publishing, 1985.

Rehg, James. *Introduction to Robotics: A Systems Approach*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985.

Robotics Institute of America Robotics Glossary. Dearborn, MI: Robotics Institute of America, 1984.

Vail, Peter S. *Computer Integrated Manufacturing*. PWS-KENT Publishing Co., 1988.

Orientation
Unit 1

Objective Sheet

Unit Objective

After completing this unit, the student should be able to identify the basic elements of a robotic system, draw work envelopes and a work cell, and survey for career opportunities in the robotics industry. The student should demonstrate these competencies by completing the assignment sheets and by scoring a minimum of 85 percent on the written test.

Specific Objectives

After completing this unit, the student should be able to:

1. Match terms related to robotics with their correct definitions.
2. Select true statements concerning the history of robotics.
3. Select true statements concerning the introduction of computers.
4. Identify the basic elements of a robotic system.
5. List various applications of robots.
6. Distinguish between reprogrammable and multifunctional robots.
7. Match the parts of a work envelope with the correct descriptions.
8. Identify the basic types of work envelopes.
9. List causes of unexpected robot movement.
10. List injuries possible with unexpected robot movement.
11. Complete statements concerning hazards related to using end-of-arm tooling.
12. Match protective safety devices for robotic systems with the correct descriptions.
13. Match various careers in the robotics industry with their correct duties.
14. Draw work envelopes. (Assignment Sheet 1)
15. Draw a work cell and locate all safety devices. (Assignment Sheet 2)
16. Survey local industries for robotics use. (Assignment Sheet 3)
17. Survey a career in robotics. (Assignment Sheet 4)

Orientation
Unit 1

Suggested Activities

Instructional Plan

Preparation

1. Read the unit carefully and plan for instruction.

2. Review Teaching Suggestions section that follows. Plan for classroom activities.

3. Plan for students with special needs.

4. Make transparencies from the transparency masters included with this unit. These appear in the teacher edition only and are designed to be used with the following objectives:

   TM 1—Basic Elements of a Robotic System (Objective 4)
   TM 2—Parts of a Work Envelope (Objective 7)

5. Obtain films, videotapes, and other resources to supplement instruction of this unit. See ordering information in the Suggested Supplemental Resources section that follows.

6. Develop teaching plan. Adjust for different learning styles.

7. Make copies of Unit Evaluation Form.

Delivery and Application

8. Provide students with unit of instruction.

9. Discuss unit and specific objectives.

10. Discuss information sheet. Implement teaching plan to localize, supplement, and personalize the unit. Reinforce basic academic and workplace skills when applicable.

11. Discuss the assignment sheets. Review criteria for evaluation of these activities.

Evaluation

12. Discuss the use of the Unit Evaluation Form with students. Discuss the rating scale that will be used for student evaluation.

13. Make copies of the written test. Add or modify test items as needed.

Suggested Activities

14. Give written test.

15. Compile assignment sheet ratings and written test scores on the Unit Evaluation Form. Include any additional assignments.

16. Reteach and retest as required.

Teaching Suggestions

Note: Skill areas appearing in boldface type in the Teaching Suggestions refer to the academic and workplace skills identified by the American Society for Training and Development (ASTD) and the U.S. Department of Labor. These have been adapted by MAVCC.

1. Show a video dealing with robotics. Use as an introduction or for added interest. See the "Suggested Supplemental Resources" section for information about possible videos. You may want to develop your own videos or slide series that deal with the activities of your previous classes throughout the year or videos of industry tours that you have taken. Videos help reinforce **listening** skills and can serve as **motivation** for students to learn more about robotics.

2. Discuss changes you have seen in robots and their increased use by industries in the last few years. Discussions help reinforce **listening skills**.

3. Have students locate the basic elements of a robotic system on the system(s) used in your classroom/laboratory. These basic elements are described in Objective 4. This helps students correlate the unit content with their local system.

4. Have students locate the safety devices used on your classroom/laboratory robotic system. These devices are outlined in Objective 12. Safety is highly valued by the robotics industry. Emphasizing industry standards and expectations reinforces **organizational effectiveness skills**.

5. Discuss with class your personal stories about injuries that have happened to you, fellow workers, or former students when they were working near robots. Relate the seriousness of their injuries. Have students predict the time and money lost because of these accidents. This discussion can reinforce **math foundation skills, communication skills**, and **organizational effectiveness skills**.

6. Have students discuss ways that some accidents can be prevented. You may want to have students elect a safety marshall who can help you monitor safety rule violations. Have the class come to a consensus on reasonable penalties for breaking safety rules. These discussions can reinforce **communication skills, adaptability skills (creative thinking and problem skills), motivation, group effectiveness skills**, and **influence skills**.

Suggested Activities

7. Display safety posters that apply to robotics. These could be ones made commercially or ones made by students. These are good reminders to be safe.

8. Additional suggestions for Assignment Sheet 1

   a. Divide the class into small groups and assign only one problem to each group—either Part A or Part B. This reinforces **teamwork** and **interpersonal relations skills**.

   b. After the work envelope is drawn for the class robot(s), display the best drawings.

9. Additional suggestions for Assignment Sheet 2

   a. Provide grid paper (various scales) or drafting tools so students can draw the work cells to scale.

   b. You may also want to physically map out the work cell on the classroom/laboratory floor using color paper and tape. This reinforces visual learning.

10. Additional suggestions for Assignment Sheet 3

    a. Allow class time for students to discuss their findings and to point out local uses of robots.

    b. An alternative to having each student call local industries for surveys would be to have local industry representatives come to the classroom. Students could then ask the survey questions (and others) at the same time.

    c. Another alternative would be to have a local industry representative answer the survey questions for the whole class during a class tour arranged by the instructor.

    All of these activites can help to reinforce **communication skills** as well as give students more **career development** information.

11. Additional suggestions for Assignment Sheet 4

    a. Provide written resources about employment opportunities in the robotics industry. Check with the school guidance office for more information.

    b. Arrange for the school counselor or placement director to discuss with the class as a whole information about careers in robotics.

    c. Arrange for a former student or an employee of a local industry using robotics to discuss how they prepared for their current position in robotics, present and expected earnings, and opportunities for advancement.

    All of these activities can help to reinforce **communication skills** and **personal management skills**.

Suggested Activities

Resources Used in Developing This Unit

1. Engelberger, Joseph F. *Robotics In Practice*. Great Britain: AMACOM, 1982.

2. Hoekstra, Robert L. *Robotics and Automated Systems*. Cincinnati, OH: South-Western Publishing Co., 1986.

3. Malcolm, Douglas R., Jr. *Robotics: An Introduction*. Boston: Breton Publishers, 1985.

4. Rehg, James. *Introduction to Robotics*. Barrington, IL: TPC Training Systems/Technical Publishing, 1985.

5. Rehg, James. *Introduction To Robotics: A Systems Approach*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985.

Suggested Supplemental Resources

1. *Robotics Explained*, a series of four videotapes. The following are especially suited to this unit:

   a. *Robotic Nomenclature*—Covers basic parts of a robot, degrees of freedom, work envelopes

   b. *Robots in the Workplace*—Describes how robots are used by industries

   These videotapes are available from:

   TPC Training Systems
   750 Lake Cook Road
   Buffalo Grove, IL 60089
   Phone 800-837-8872

2. *Robotics: The Future is Now*. 16mm or videotape, 20 min., 1984.

3. *Robots: The Computer at Work*. 16mm or videotape, 22 min, 1985.

   Tapes listed as 2 and 3 above are available from:

   AIMS Media
   6901 Woodley Avenue
   Van Nuys, CA 91406-4878
   Phone 800-367-2467

Suggested Activities

4. Robotics tutorial software by *SHOPWARE Educational Systems*, copyright 1989. Each unit includes lessons and quizzes on copyable disks, written handout quizzes, teacher helps, and a vinyl binder.

   a. *Robotics Fundamentals*

   b. *History of the Robot*

   c. *Career Opportunities in Robotics*

   These software lessons are available in the following formats: Apple II, 128K 5¼"; Apple II, 128K 3½"; IBM, 128K 5¼"; IBM, 128K 3½" (IBM PC needs to be CGA graphics compatible); or Macintosh. They are available from:

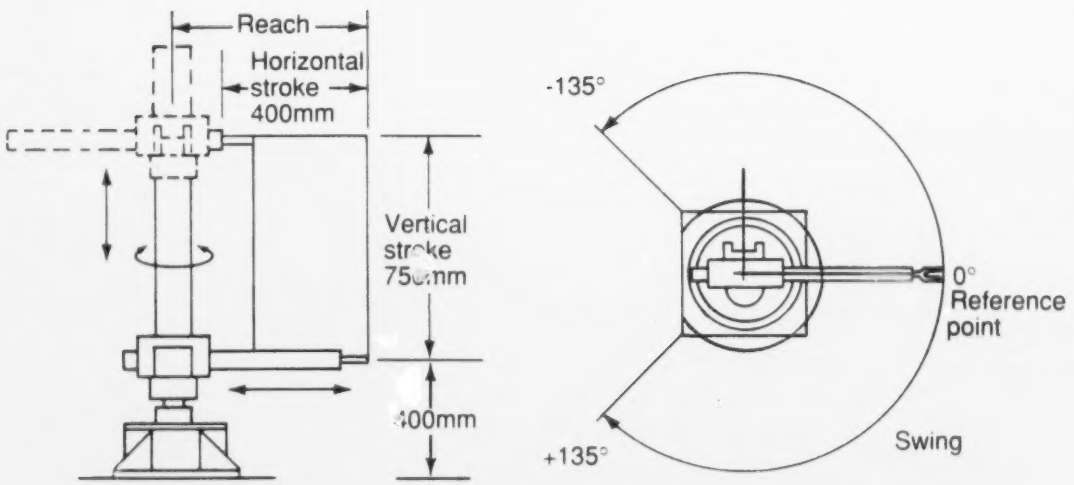
   Teaching Aids Inc.
   P.O. Box 1798
   Costa Mesa, CA 92628
   Phone 714-548-9321

Orientation
Unit 1

Answers to Assignment Sheets

Assignment Sheet 1

Part A



a. Elevation (Front) View **b. Plan (Top) View**

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Part B—Evaluated according to class robot

Assignment Sheets 2 - 4—Evaluated according to the stated criteria.

Orientation
Unit 1

Answers to Written Test

1. a. 6 d. 7
   b. 4 e. 5
   c. 2 f. 8

2. a, b, c, e, g, i, j

3. b, c, d

4. a. Controller
   b. Power source
   c. Manipulator
   d. End-of-arm tooling (end effector)

5. Any four of the following:

   a. Material handling
   b. Machine loading/unloading
   c. Die casting
   d. Welding
   e. Assembly
   f. Spray painting

6. a. R
   b. M

7. a. 5
   b. 6
   c. 4
   d. 2

8. a. Spherical
   b. Cylindrical
   c. Rectangular

9. Any three of the following

   a. Program errors
   b. Hardware failures
   c. Power failures or interruptions with automatic restarts
   d. Switching to automatic mode
   e. Improper training of operator

Answers to Written Test

10. Any two of the following:

    a. Cuts or puncture wounds
    b. Bruises or crushing blows
    c. Pinches
    d. Burns

11. a. Pinch
    b. Burns
    c. Lungs

12. a. 6
    b. 3
    c. 1
    d. 2
    e. 5

13. a. 2
    b. 4
    c. 3
    d. 1

Orientation
Unit 1

Written Test

Name _____ Score _____

1. Match terms with their correct definitions by writing the corresponding numbers on the blanks provided.

_____a.	The science of building, designing, and applying robots to a task	1. Appendage
_____b.	A sequence of coded instructions that tell the machine what to do	2. Axis
_____c.	A straight line about which a figure rotates	3. Material
_____d.	The entire work environment that the robot uses to perform its task	4. Program
_____e.	A reprogrammable, multifunctional manipulator designed to move parts, materials, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks	5. Robot
_____f.	The work area which describes the reach of the robot	6. Robotics
		7. Work cell
		8. Work envelope

2. Select true statements concerning the history of robotics by writing an "X" on the blank before each true statement.

_____a. Joseph Jacquard invented a textile machine called a programmable loom in 1801.

_____b. In 1830, Christopher Spencer designed a cam-operated lathe.

_____c. In 1892, Seward Babbitt designed a motorized crane equipped with a gripper to remove ingots from a furnace.

_____d. The first reference to the word *robot* appeared in a play written by an American who introduced the word to mean "one in subservient labor" in 1921.

_____e. Willard Pollard and Harold Roselund designed a programmable paint-spraying mechanism in 1938.

_____f. In 1944, the first large electronic computer was built by two American scientists.

_____g. In 1954, George Devol designed the first programmable robot.

_____h. In 1984, General Motors installed the first industrial robot on a production line.

_____i. Stanford Research Institute (SRI) built and tested a mobile robot with vision capability in 1968. They called it Shakey.

_____j. "T3," The Tomorrow Tool, the first minicomputer-controlled industrial robot, was developed by Richard Hohn for Cincinnati Milacron Corporation in 1973.

3. Select true statements concerning the introduction of computers by writing an "X" on the blank before each true statement.

_____a. In 1926, the first two robots were designed and tested at the University of Pennsylvania and at the Massachusetts Institute of Technology. These two robots were called the ENIAC I and II.

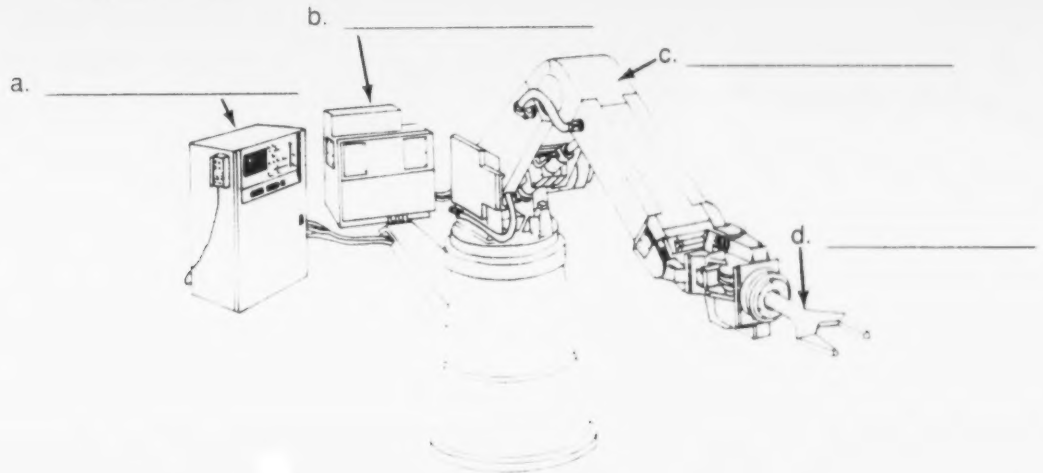
_____b. In 1948, a book called *Cybernetics, or Control and Communication in the Animal and Machine* was published. Cybernetics is the study of machines that can analyze their surroundings, adjust their operation to fit the surroundings, and communicate with other systems when necessary.

_____c. In 1952, the first servo-controlled machine tool was built at Massachusetts Institute of Technology. This signaled the beginning of computer control in the machine industry.

_____d. In the 1970s the integrated circuit (IC) chip was manufactured and with additional development then came the appearance of the microprocessor. Using the microcomputer for control, robots could become programmed with a high-level computer language.

Written Test

4. Identify the basic elements of a robot system by writing the correct term in the blanks provided below.



5. List four applications of robots.

   a. _____

   b. _____

   c. _____

   d. _____

6. Distinguish between reprogrammable and multifunctional by placing an "R" for reprogrammable and an "M" for multifunctional next to the correct description.

   _____a. The robot's actions are controlled by a stored program. The program can be changed according to the requirements of the job.

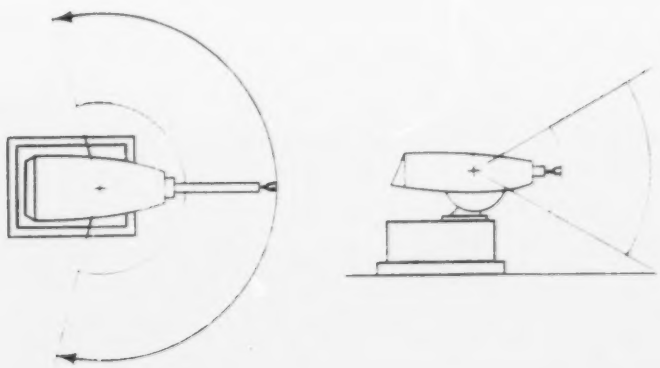
   _____b. The robot is capable of performing more than one function. The robot can be used in various manufacturing jobs in a factory or in different industries.

Written Test

7. Match the parts of a work envelope with the correct descriptions.

_____a.	The robot's rotation about the base	1. Pitch
_____b.	The point at which the robot starts its motion	2. Reach
_____c.	The extent of vertical and horizontal travel that the robot's manipulator uses	3. Roll 4. Stroke
_____d.	The distance between the center of the robot and the farthest point the manipulator arms extends, including the end-of-arm tooling	5. Swing 6. Zero reference point

8. Identify the basic types of work envelopes shown.



a. _____

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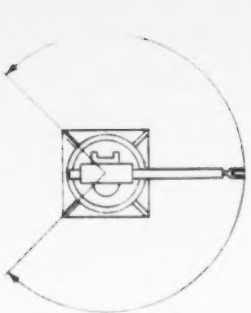
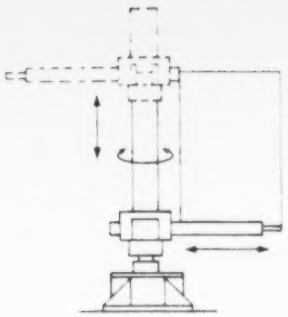
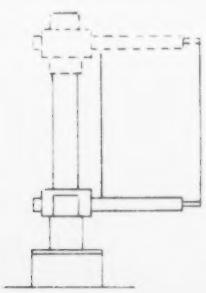
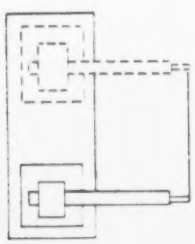
Written Test





b. _____





c. _____

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9. List three causes of unexpected robot movement.

a. _____

b. _____

c. _____

10. List two injuries possible with unexpected robot movement.

a. _____

b. _____

11. Complete statements concerning hazards related to using end-of-arm tooling by circling the correct answers.

    a. Grippers can (burn. pinch) you.

    b. Welding electrodes and lasers can cause serious (burns. cuts).

    c. Fumes from sprayers can cause damage primarily to your (heart. lungs).

12. Match protective safety devices for robotic systems on the right with the correct descriptions.

    _____a. Colored or flashing object that tells the operator about the robot s condition or stage of operation

    _____b. Removes all power to the robot system: may be valves or switches

    _____c. Physical object that keeps people out of the robot's work envelope

    _____d. Manually-operated button which stops the robot system. places the robot in a safe state. and maintains that state until a safe intentional start is made

    _____e. Detects the intrusion of a person or object within a given area and stops the operaton of the robot system

    1. Barrier
    2. Emergency stop
    3. Full system shutdown switch
    4. Hard stop
    5. Presence sensing device
    6. Visual indicator light

13. Match various careers in the robotics industry with their correct descriptions by writing the corresponding numbers on the blanks provided.

    _____a. Lays out. assembles. installs. maintains. and tests electrical equipment and wiring used for robot communications and power

    _____b. Conducts research and development activities in relation to the design. manufacture. testing. and application of electrical and electronic components. products. and systems

    1. Robotics technician
    2. Electrician
    3. Computer service technician
    4. Electronics engineer

_____c. Installs, maintains, and repairs electronic computers and computer-related machines used in the robotics industry

_____d. Installs, services, troubleshoots, maintains, and repairs robots and robotic systems; also assists in the application and design of robotics and in their manufacture and testing

***Permission to duplicate this test is granted.**

Orientation
Unit 1

Unit Evaluation Form

Student Name _____ Unit Rating _____

Assignment Sheet 1—Draw Work Envelopes Rating _____

Comments: _____

_____

Assignment Sheet 2—Draw a Work Cell and Locate all Safety Devices Rating _____

Comments: _____

_____

Assignment Sheet 3—Survey Local Industries for Robotics Use Rating _____

Comments: _____

_____

Assignment Sheet 4—Survey a Career in Robotics Rating _____

Comments: _____

_____

Written Test Scores

Pretest _____ Posttest _____ Other _____

Other _____

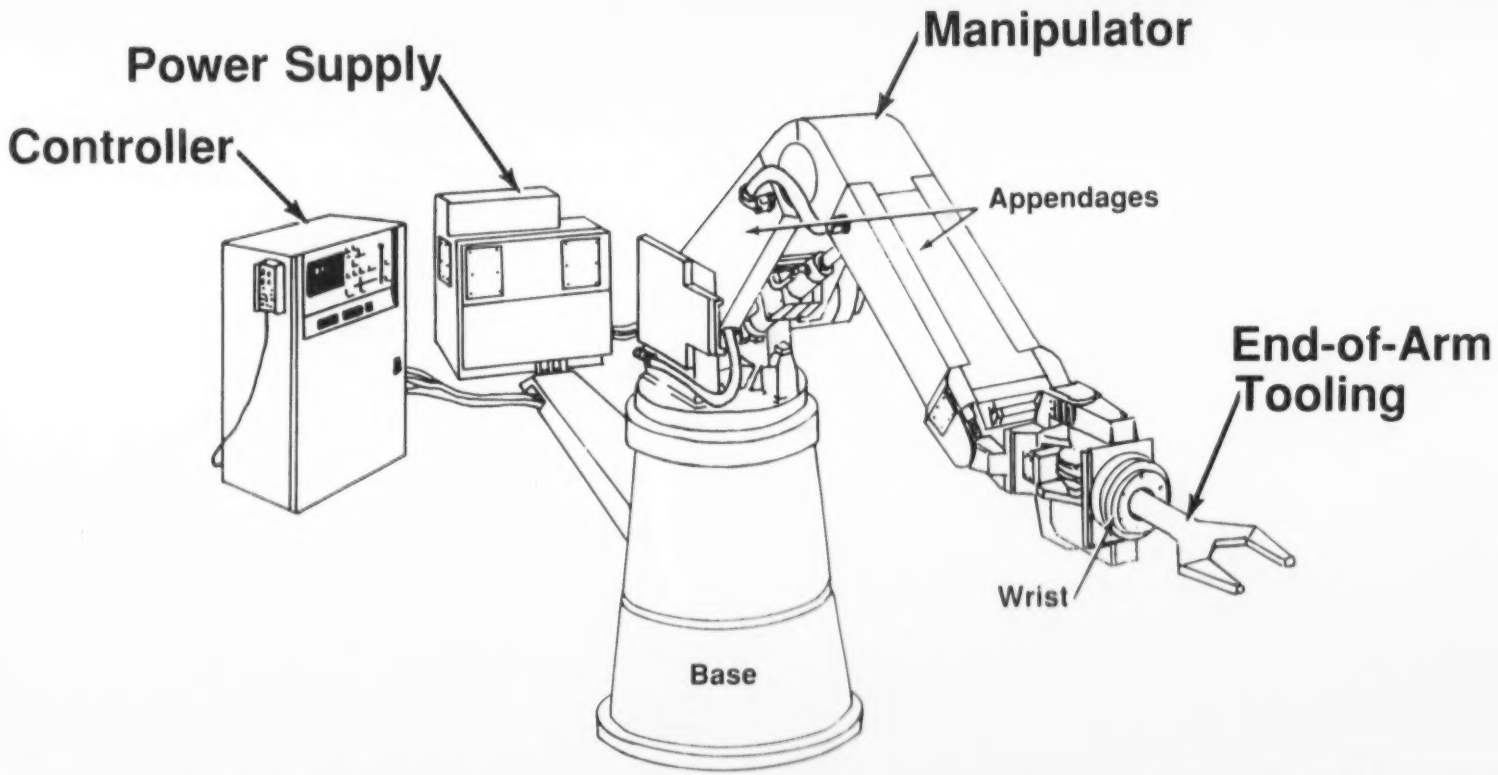
_____

Teacher Signature _____ Date _____

Student Signature _____ Date _____

*Permission to duplicate this form is granted.

Basic Elements of a Robotic System



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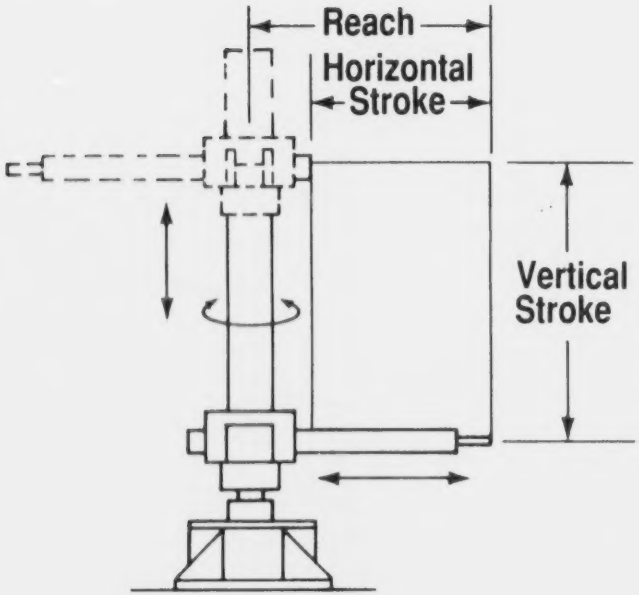
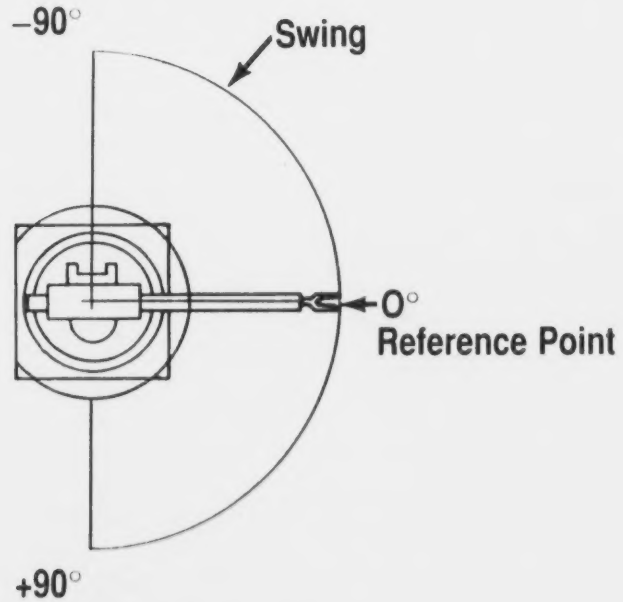
Parts of a Work Envelope



Elevation (Front) View



Plan (Top) View

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Orientation
Unit 1

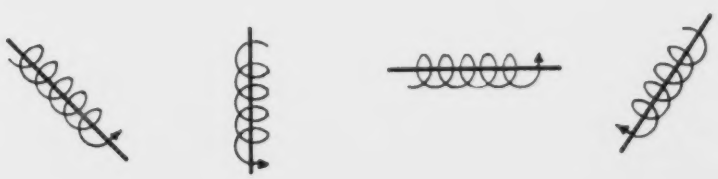
Information Sheet

1. Terms and definitions

a. **Appendage** — A smaller part attached to a larger part such as an arm attached to a body

b. **Axis** — A straight line about which a figure rotates

Figure 1



c. **Material** — Something that may be worked into a more finished form

Note: This may be raw or partially finished material.

d. **Program** — A sequence of coded instructions that tell the machine (especially a computer) what to do

e. **Robot** — A reprogrammable, multifunctional manipulator designed to move parts, materials, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks

f. **Robotics** — The science of building, designing, and applying robots to a task

g. **Work cell** — The entire work environment that the robot uses to perform its task

Note: The controller, the robot manipulator, work tables, safety features, and conveyors may all be included in the work cell.

h. **Work envelope** — The work area which describes the reach of the robot

Information Sheet

2. History of robotics

a. Joseph Jacquard invented a textile machine called a programmable loom in 1801.

b. In 1830, Christopher Spencer designed a cam-operated lathe.

c. In 1892, Seward Babbitt designed a motorized crane equipped with a gripper to remove ingots from a furnace.

d. The first reference to the word *robot* appeared in a play written by a Czechoslovakian who introduced the word to mean "one in subservient labor" in 1921.

e. Willard Pollard and Harold Roselund designed a programmable paint-spraying mechanism in 1938.

f. In 1946, the first computers were designed and tested at the University of Pennsylvania and Massachusetts Institute of Technology.

g. In 1954, George Devol designed the first programmable robot.

h. In 1962, General Motors installed the first industrial robot on a production line.

i. Stanford Research Institute built and tested a mobile robot with vision capability in 1968. They called it Shakey.

j. "T3," The Tomorrow Tool, the first minicomputer-controlled industrial robot, was developed by Richard Hohn for Cincinnati Milacron Corporation in 1973.

3. Introduction of computers

a. In 1946, the first two computers were designed and tested at the University of Pennsylvania and at the Massachusetts Institute of Technology. These two computers were called the ENAIC and Whirlwind which controlled industrial automation and robots.

b. In 1948, a book called *Cybernetics, or Control and Communication in the Animal and Machine*, was published. Cybernetics is the study of machines that can analyze their surroundings, adjust their operation to fit the surroundings, and communicate with other systems when necessary.

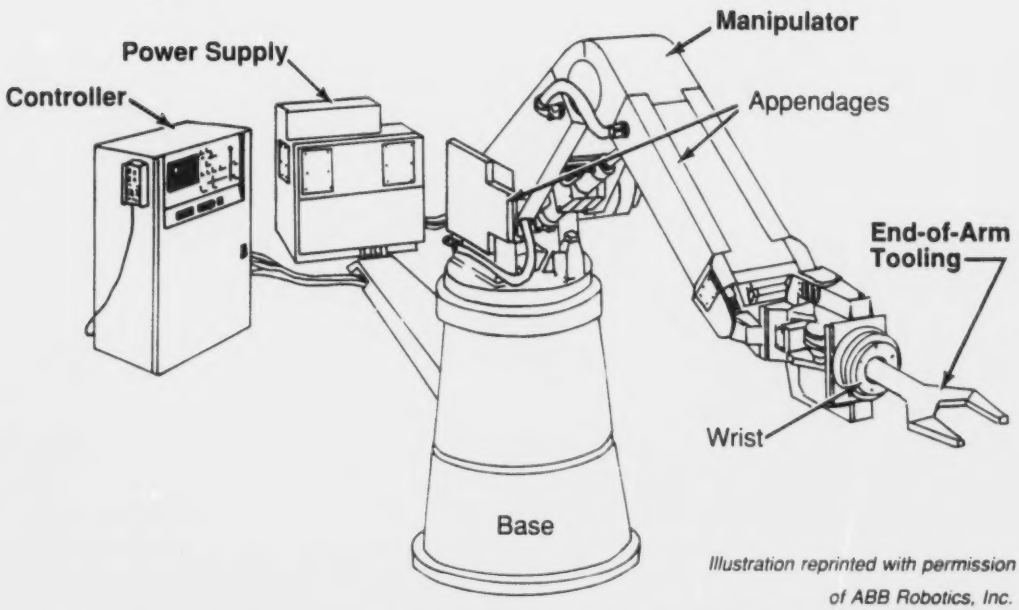
c. In 1952, the first numerically controlled machine tool was built at the Massachusetts Institute of Technology. This signaled the beginning of computer control in the machine industry.

d. In the 1970s the integrated circuit (IC) chip was manufactured, and with additional development then came the appearance of the microprocessor. Using the microcomputer for control, robots could become programmed with a high-level computer language.

Information Sheet

4. Basic elements of a robotic system

Figure 2



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a. **Manipulator** — Robot's arm(s) which performs the physical work of the robotic system; consists of a base, appendages with axes to allow movement, and a wrist to allow additional axis motion and tasks.

b. **Controller** — The most complex part of a robotic system which controls the robot's arm and interfaces with teaching devices such as teach pendants and computers to perform communication tasks through the use of input and output ports.

c. **Power source** — Supplies power to the controller and the manipulator.

Note: The power may hydraulic, pneumatic, or electrical (AC or DC).

d. **End-of-arm tooling** (end effector) — Device or tool connected to the end of the manipulator which gives the robot added capabilities

Examples: Grippers, welding or paint guns, grinders, vacuum devices, laser cutting tools

Information Sheet

5. Applications of robots

a. **Material handling** — Moving materials throughout the work cell or manufacturing plant

b. **Machine loading/unloading** — Loading industrial machines such as lathes or presses, allowing them to perform a function, and then removing the product and inspecting it for defects

c. **Die casting** — Injecting molten metal into various dies to form parts, removing the parts from the dies, and inspecting them for defects and specifications

d. **Welding** — Conducting arc and spot welding operations

e. **Assembly** — Combining or fitting together various parts to make a complete unit

f. **Spray painting** — Painting parts and products with pressurized paint guns

Note: The robot replaces humans to protect them from the hazards of airborne paint particles and the undesirable working environment.

6. Reprogrammable and multifunctional robots

a. **Reprogrammable** — The robot's actions are controlled by a stored program. The program can be changed according to the requirements of the job.

b. **Multifunctional** — The robot is capable of performing more than one function. The robot can be used in various manufacturing jobs in a factory or in different industries.

Example: Suppose a robot is to be used in die casting operations. A gripper that can hold parts produced in a die-casting machine must be mounted on the robot's arm. The robot must also be programmed to unload the die-cast parts. Suppose later that a trim press is added to the die-casting area. The robot can be reprogrammed with additional moves to take the die-cast parts to the press to be trimmed, thus becoming multifunctional. If in the future die-casting is eliminated in the plant, the robot can be moved to another location and reprogrammed and/or retooled to perform another function.

Information Sheet

7. Parts of a work envelope

a. **Zero reference point** — The point at which the robot starts its motion

Note: The zero reference point is determined by the designer of the robot according to its function and task.

b. **Reach** — The distance between the center of the robot and the farthest point the manipulator arm extends, including the end-of-arm tooling

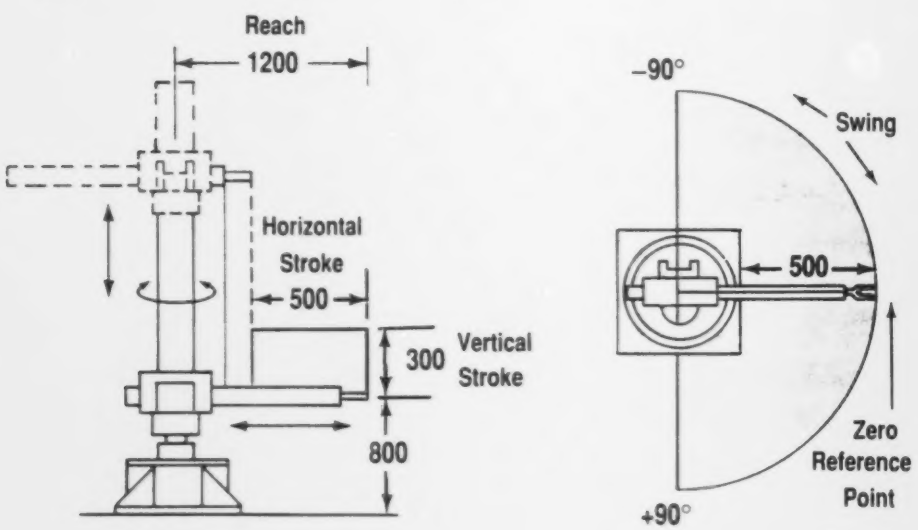
c. **Stroke** — The extent of vertical and horizontal travel that the robot's manipulator uses

Note: This measurement is taken from the manipulator wrist flange. If a spraying or welding tool (end effector) is attached to the robot, the work envelope will increase in size.

d. **Swing** — The robot's rotation about the base

Note: Swing is measured from zero reference point, clockwise in the positive (+) direction and counterclockwise in the negative (–) direction. It can range from 0 to 360 degrees in either direction.

Figure 3



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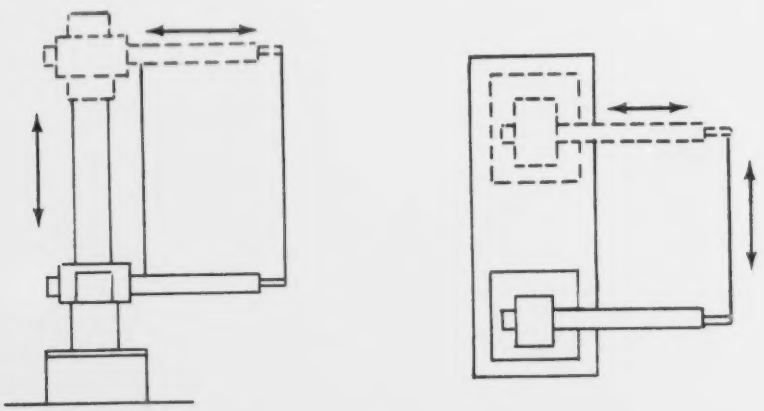
Information Sheet

8. Basic types of work envelopes

a. **Rectangular** — Movement along the vertical and horizontal axes that shows a rectangular shape

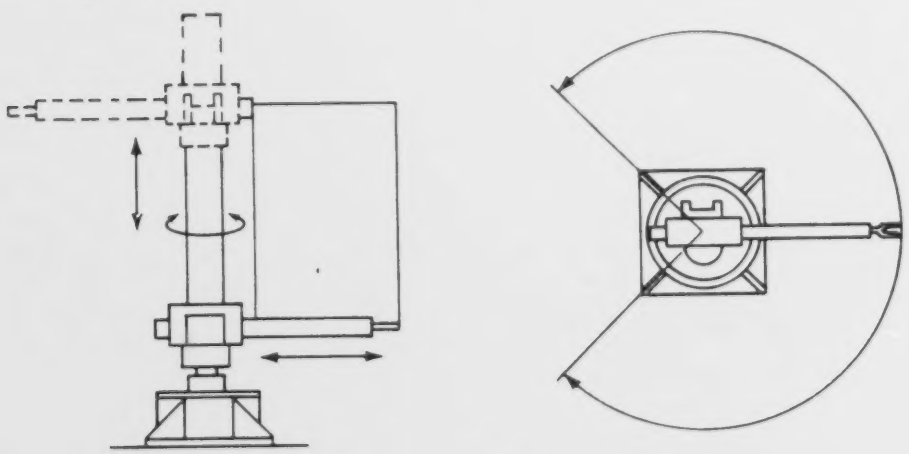
Figure 4



Elevation (Front) View **Plan (Top) View**

b. **Cylindrical** — Movement along the vertical and horizontal axes and pivots or turns at the center of its base that shows a cylindrical shape

Figure 5



Elevation (Front) View **Plan (Top) View**

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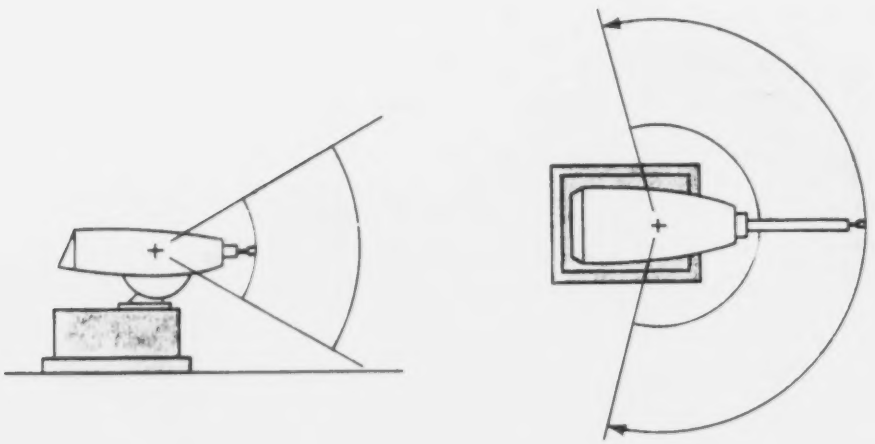
Information Sheet

c. **Spherical** — No vertical or horizontal movement but pivots and turns at the center of the base that shows a sphere or ball shape

Figure 6



Elevation (Front) View **Plan (Top) View**

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9. Causes of unexpected robot movement

a. Program errors

b. Hardware failures

c. Power failures or interruptions with automatic restarts

d. Switching to automatic mode

e. Improper training of operator

Note: Effective design of the work cell and proper training on the robot system will minimize the chance of unexpected robot movement.

10. Injuries possible with unexpected robot movement

a. Cuts or puncture wounds

b. Bruises or crushing blows

c. Pinches

d. Burns

Note: Any person in the work envelope at the time of the unexpected movement can be injured by the robot, by the product being held by the robot, or by the robot's manipulator.

Information Sheet

11. Hazards related to using end-of-arm tooling

a. **Grippers** can pinch or bruise you. If the grippers malfunction, the object being held could be dropped or thrown by the gripper resulting in serious injury to anyone in the line of movement.

b. **Grinding wheels** can crush or cut you, causing serious damage to any body part in contact.

c. **Welding electrodes** can cause serious burns, both to skin and eyes.

d. **Lasers** can also cause burns to skin and eyes.

e. **Sprayers or spray guns** release paints and other products under high pressure. If their fumes and vapors are inhaled, they can cause damage to eyes, nose, mouth, throat, and lungs. Products sprayed on the skin can cause serious damage depending on the type of product involved.

12. Protective safety devices for robotic systems

a. **Emergency stop** — Manually-operated button which stops the robot system, places the robot in a safe state, and maintains that state until a safe intentional start is made

Note: An emergency stop (E-stop) may be in the form of a cable which is ultimately attached to a button. This type of E-stop may be used around wide roller operations and pinch (nip) points.

b. **Full system shutdown switch** — Removes all power to the robot system; may be valves for hydraulic or pneumatic systems or switches for electrical systems

c. **Presence sensing device** — Detects the motion of a person or object within a given area and stops the operation of the robot system

d. **Hard stop** — Structural object which limits the extension of any robot component beyond a designated area

e. **Visual indicator light** — Colored or flashing light that tells the operator about the robot's condition or stage of operation

f. **Barrier** — Physical object that keeps people out of the robot's work envelope

Information Sheet

13. Careers in the robotics industry

a. **Electrician**

(1) Lays out, assembles, installs, maintains, and tests electrical equipment and wiring used for robot communications and power.
(2) Electricians work primarily indoors and should like using tools and equipment.
(3) This trade can be learned at most technical schools and colleges.

b. **Electronics engineer**

(1) Conducts research and development activities in relation to the design, manufacture, testing, and application of electrical and electronic components, products, and systems.
(2) Usually a college bachelor's degree is needed for this career.

c. **Computer service technician**

(1) Installs, maintains, and repairs electronic computers and computer-related machines used in the robotics industry.
(2) This trade can be learned at many technical, junior, or community colleges.

d. **Robotics technician**

(1) Installs, services, troubleshoots, maintains, and repairs robots and robotic systems. Also assists in the application and design of robotics and in their manufacture and testing.
(2) Technical, junior, or community college and on-the-job training are generally needed for this trade.

Note: Not all industries which use robots hire robotics technicians to maintain their robots. Many industries use people with a combination of career trainings listed above to service their robots.

Orientation
Unit 1

Assignment Sheet 1—Draw Work Envelopes

Name _____ Overall Rating _____

Evaluation criteria	Rating
Work envelope for Part A is drawn correctly	_____
Work envelope for Part B is drawn correctly	_____
Parts are labeled correctly	_____

Directions: Using the information in Part A, construct a work envelope for both the elevation and plan view in Figure 1 of the robot as prescribed. Then draw a work envelope for the robotic system used in your classroom or laboratory for Part B.

Part A: Given Robot

Robot Characteristics:

1. Manipulator stroke

Vertical	750 millimeters
Horizontal	400 millimeters

2. Manipulator swing

Counterclockwise	–135 degrees
Clockwise	+135 degrees

3. Manipulator from floor — 400 millimeters

Assignment Sheet 1

1. Using Figure 1a that follows; a compass, ruler, and No. 2 pencil; and the given robot characteristics, construct the elevation view work envelope for this robot.

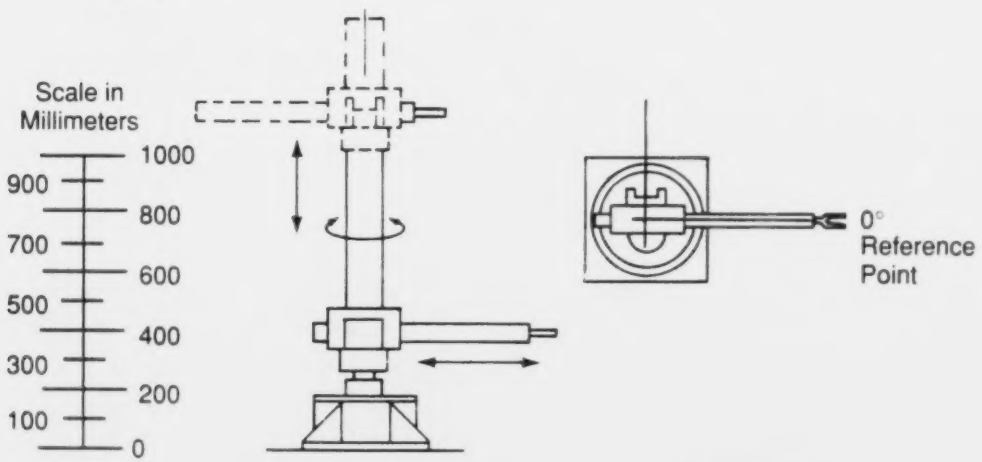
2. Using Figure 1b that follows and the same materials and robot characteristics, construct the plan view work envelope for this robot.

3. Properly label the distance the manipulator is from the floor at the starting position on Figure 1.

4. Properly label the "Manipulator Reach" on Figure 1.

5. Properly label the "Stroke" and "Swing" of the manipulator arm on Figure 1.

Figure 1



Elevation (Front) View **Plan (Top) View**

Part B: Class Robot

1. Construct the elevation view for the robot used in your class.

2. Construct the plan view for the robot used in your class.

3. Properly label reach, stroke, and swing on your drawings.

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Orientation
Unit 1

Assignment Sheet 2—Draw a Work Cell and Locate All Safety Devices

Name _____ Overall Rating _____

Evaluation criteria	Rating
Work cell is drawn correctly	_____
All safety devices are located correctly on drawing	_____

Directions: Draw the work cell for the robotic system used by your class. Use grid paper provided by your instructor to draw the area to scale. Identify all major features and all protective safety devices including emergency stops, hard stops, shutdown switch, sensing devices, indicator lights, and physical barriers.

Orientation
Unit 1

Assignment Sheet 3—Survey Local Industries for Robotics Use

Name _____ Overall Rating _____

Evaluation criteria	Rating
Industries are identified	_____
Use of robotics is recorded	_____

Directions: Call your local industries and gather information about the types of robots they use in their operations. Complete the following form for each industry you talk with. Then discuss your findings in class.

Industry Survey Form

1. **Name of company:** _____

   _____

2. **Type of product produced:** _____

   _____

3. **Number of robots used:** _____

4. **Applications performed by robots:** _____

   _____

   _____

5. **Robotics careers available in their industry:** _____

   _____

Assignment Sheet 3

Industry Survey Form

1. Name of company: _____

   _____

2. Type of product produced: _____

   _____

3. Number of robots used: _____

4. Applications performed by robots: _____

   _____

   _____

5. Robotics careers available in their industry: _____

   _____

Orientation
Unit 1

Assignment Sheet 4—Survey a Career in Robotics

Name _____ Overall Rating _____

Evaluation criteria	Rating
Information is appropriate for selected career	_____

Directions: Gather all the forms you completed in Assignment Sheet 3. From question 5, choose a career that you would be interested in. Complete the following form. Then discuss your findings in class.

1. **Nature of the job** _____

_____

_____

_____

2. **Duties/Responsibilities**

_____

_____

_____

_____

_____

_____

_____

_____

Assignment Sheet 4

3. **Education/Training required** _____

_____

_____

_____

_____

4. **Earnings** _____

5. **Opportunities for employment** _____

_____

_____

_____

6. **Working conditions** _____

_____

_____

7. **Other requirements (union, age, etc.)** _____

_____

_____

_____

Nonservo Robot Operations
Unit 2

Objective Sheet

Unit Objective

After completing this unit, the student should be able to explain the basic operations, motion, and programming features of a nonservo robot and be able to use flowchart diagrams and basic ladder logic programs. The student should demonstrate these competencies by completing the assignment sheets and job sheets and by scoring a minimum of 85 percent on the written test.

Specific Objectives

After completing this unit, the student should be able to:

1. Match terms related to nonservo robot operations with their correct definitions.
2. Distinguish between the classifications of robots according to their motion control.
3. Identify the basic types of robot arm geometry.
4. Label the orientation axes of wrist rotation.
5. Select true statements concerning the characteristics of fluid power sources for nonservo robots.
6. Select characteristics of hydraulic drive systems.
7. Select characteristics of pneumatic drive systems.
8. Discuss the differences between on-line and off-line programming.
9. Select true statements concerning basic robot programming.
10. Complete statements concerning event sequence programming.
11. State the sequence of events used in determining the home position for the robot.
12. Identify basic flowchart symbols.
13. Complete statements concerning the basic principles of robotic flowcharting.

Objective Sheet

14. Match PLC components with their correct functions.

15. Select characteristics of PLC programming of nonservo robots.

16. Match terms related to PLC programming with their correct definitions.

17. Select true statements concerning the verification and identification of input and output addresses.

18. Calculate the lift capabilities of the Mercury robot. (Assignment Sheet 1)

19. Develop a flowchart for a sequence of operations. (Assignment Sheet 2)

20. Draw the work envelope for the Mercury robot. (Assignment Sheet 3)

21. Locate axes and degrees of freedom for the Mercury robot. (Assignment Sheet 4)

22. Identify limit switches, solenoid locations, and addresses for the Mercury robot. (Job Sheet 1)

23. Enter a program using event sequencing. (Job Sheet 2)

24. Enter a program to operate the Mercury robot using output reenergization. (Job Sheet 3)

25. Develop a flowchart and program for a robotic work cell application. (Job Sheet 4)

Nonservo Robot Operations
Unit 2

Suggested Activities

Instructional Plan

Preparation

1. Read the unit carefully and plan for instruction.

   Note: Students should have prior instruction on programmable logic controllers and fluid power theory. Basic terminology in the information sheet and the student supplement is only designed to be used as a review of this information.

2. Review Teaching Suggestions section that follows. Plan for classroom activities.

3. Plan for students with special needs.

4. Make transparencies from the transparency masters included with this unit. These appear in the teacher edition only and are designed to be used with the following objectives:

   TM 1—Robot Arm and Wrist Rotations (Jointed) (Objectives 3 and 4)
   TM 2—Basic Flowchart Symbols (Objective 12)

5. Obtain films, videotapes, and other resources to supplement instruction of this unit. See ordering information in the Suggested Supplemental Resources section that follows.

6. Develop teaching plan. Adjust for different learning styles.

7. Review "Instructions for Evaluating Student Performance," which follows the resources in this section of the unit. Make copies of Unit Evaluation Form, which follows the written test section.

Delivery and Application

8. Provide students with unit of instruction.

9. Discuss unit and specific objectives.

10. Discuss information sheet. Implement teaching plan to localize, supplement, and personalize the unit. Reinforce basic academic and workplace skills when applicable.

11. Discuss the assignment sheets. Review criteria for evaluation of these activities.

12. Discuss and demonstrate the job sheets. Make sure all required tools, equipment, and supplies are available. Review criteria for evaluation of these activities.

Suggested Activities

Evaluation

13. Discuss the use of the Unit Evaluation Form with students. Discuss the rating scale that will be used for student evaluation.

14. Make copies of the written test. Add or modify test items as needed.

15. Give written test.

16. Record assignment sheet ratings, job sheet ratings, and written test scores on the Unit Evaluation Form. Add any additional assignments or supplemental activities that should be part of the unit evaluation.

17. Reteach and retest as required.

Teaching Suggestions

Note: Skill areas appearing in boldface type in the Teaching Suggestions refer to the academic and workplace skills identified by the American Society for Training and Development (ASTD) and the U.S. Department of Labor. These have been adapted by MAVCC.

1. Review concepts and use of programmable logic controllers (PLCs) and fluid power theory. Basic terminology in the information sheet and the student supplement can help in reviewing this information. However, if your students have had no prior instruction on PLCs or fluid power, you will need to spend adequate time on these before students proceed with the rest of this unit.

2. Take the class on a tour of a local industry that uses nonservo robots. Discuss how they are being used. The tour would also be a good time to point out the various axes, power sources, and types of programming used.

    a. You may want to videotape the tour for use with later classes, students who may have missed the trip, or for recruitment of students into your program.

    b. After returning to the classroom, ask students questions about the tour (oral discussion) or have them summarize the main points of the tour in writing.

    c. The tour reinforces **group effectiveness skills** and the follow-up discussion and review reinforces **writing foundation skills** and **communication skills**.

3. Use poster paper to cut out the basic flowchart symbols. These could be displayed on the bulletin board or used as flash cards.

Suggested Activities

4. Show actual examples of the two methods of flowcharting used for nonservo applications.

5. Provide gridded paper and flowchart symbol templates for students to use in the assignment and job sheets requiring them to draw flowcharts.

6. The Mercury robot was used as the basis for the assignment and job sheets in this unit. The laboratory manuals covering the Mercury robot are available from Amatrol, Inc. Refer to the "Suggested Supplemental Resources" that follow for ordering information. If you plan to use another robot in your course, you will need to write substitute assignment and job sheets that cover similar tasks.

7. Remove the covers from the Mercury Robot and discuss with class the placement of the hard stops and adjustment procedures.

8. Prior to students beginning Assignment Sheet 1, discuss with them the following concepts:

   a. Importance of determining lift capabilities of nonservo robots.

   b. End of stroke feedback employed by the Mercury.

Resources Used in Developing This Unit

1. Engelberger, Joseph F. *Robotics in Practice*. Great Britain: AMACOM, 1982.

2. Hoekstra, Robert L. *Robotics and Automated Systems*. Cincinnati, OH: South-Western Publishing Company, 1986.

3. Malcolm, Douglas R., Jr. *Robotics: An Introduction*. Boston, MA: Breton Publishers, 1985.

4. Rauh, Bob and Stan Kaltwasser. *Programmable Logic Controllers*. Stillwater, OK: Mid-America Vocational Curriculum Consortium, 1990.

5. Rehg, James. *Introduction to Robotics*. Barrington, IL: TPC Training Systems/Technical Publishing, 1985.

6. Rehg, James. *Introduction to Robotics: A Systems Approach*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985.

Suggested Activities

Suggested Supplemental Resources

1. Laboratory manuals needed for assignment and job sheets.

   a. *Mercury Pneumatic Robot Laboratory Manual--B672*. Copyright 1991.

   b. *Mercury Robot Control Laboratory Manual--22600*. Copyright 1991.

   The Mercury manuals are available from:

   Amatrol, Inc.
   P.O. Box 2697
   Jeffersonville, IN 47131
   Phone 812-288-8285

   Note: Amatrol has many other technical publications and training courses which may be useful to instructors. Contact your local representative for more information or the main office above.

2. *Robots: Selection and Installation*, a series of four videotapes. The following are especially suited to this unit:

   a. *Robotic Design*—Covers power systems, classes of robots, and types of robot arm geometry, 14 min.

   b. *Installing and Programming*—Identifies programming procedures. 14 min.

   These videotapes are available from:

   TPC Training Systems
   750 Lake Cook Road
   Buffalo Grove, IL 60089
   Phone 800-837-8872

Instructions For Evaluating Student Performance

When the student is ready to perform a specific task, obtain a copy of the job sheet which may be found in either the teacher or student edition. Then observe the student performing the procedure.

Process evaluation—Place a mark in the box to the left of each designated checkpoint if the student has satisfactorily achieved the step(s) for each checkpoint area. If the student is unable to correctly complete the procedure, have the student review the materials and try again.

Suggested Activities

Product evaluation—Once the student has satisfactorily completed the procedure, rate the student product (outcome) using the criteria which have been provided as part of the job sheet. If the student's product is unacceptable, have the student review the materials and submit another product for evaluation.

Sample performance evaluation keys have been provided below. Many other keys are available. Select one rating (grading scale) which best fits your program needs.

Option A

4 - Skilled—Can perform job with no additional training.
3 - Moderately skilled—Has performed job during training program; limited additional training may be required.
2 - Limited skill—Has performed job during training program; additional training is required to develop skill.
1 - Unskilled—Is familiar with process, but is unable to perform job.

Option B

Yes—Can perform job with no additional training.

No—Is unable to perform job satisfactorily.

Nonservo Robot Operations
Unit 2

Answers to Assignment Sheets

Assignment Sheet 1

1. $A = (D^2)\ (.7854)$
   $A = (1.125)^2\ (.7854)$
   $A = (1.266)\ (.7854)$
   $A = .994\ in^2$
   Combined lift area is: $.944 \times 2 = \underline{1.988\ in^2}$

2. $F = PA$
   $F = (80)\ (1.988)$
   $F = \underline{159\ lbs}$

3. 159 lbs
   <u>– 3 lbs</u>
   <u>156 lbs</u>

4. 156 lbs
   <u>–68 lbs</u>
   <u>88 lbs lift capability</u>

5. $L = \dfrac{PSI \times D}{2\pi}$

   $L = \dfrac{(80)\ (4)}{(2)\ (3.14)}$

   $L = \dfrac{320}{6.28}$

   $L = \underline{50.9\ Inch\ lbs}$

6. a. Inside Turning Radius Torque

   $L = F/R$

   $L = \dfrac{50.9}{15}$

   L inside = <u>3.39 Inch lbs</u>

b. Outside Turning Radius Torque

$L = F/R$

$L = \frac{50.9}{27}$

L inside = 1.89 Inch lbs

7. a. No
   b. Yes
   c. No

8. $A = (D^2)\ (.7854)$
   $A = (1.125)^2\ (.7854)$
   $A = (1.266)\ (.7854)$
   $A = .994\ In^2$

   $F = PA$
   $F = (80)\ (.994)$
   $F = 79.52$ lbs

   79.52
   −3.00
   76.52 lbs

9. Rod area
   $A = (D^2)\ (.7854)$
   $A = (.375)^2\ (.7854)$
   $A = (.141)\ (.7854)$
   $A = .110\ In^2$

   Piston Area $.994\ In^2$
   Rod Area $.110\ In^2$

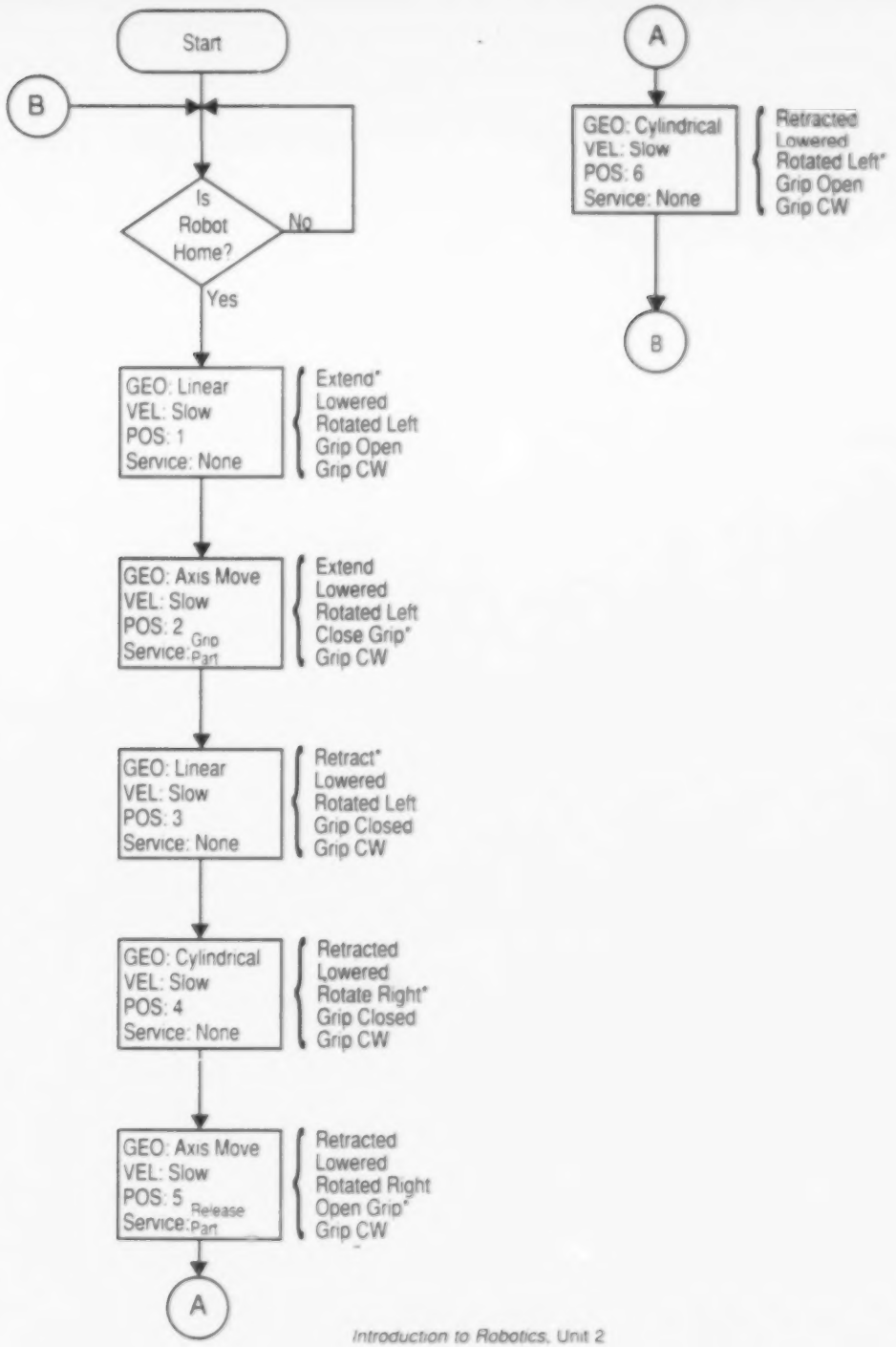
   .994
   −.110
   .884

   $F = PA$
   $F = (80)\ (.884)$
   $F = 70.7$ lbs

   70.7
   −3.0
   67.7 lbs

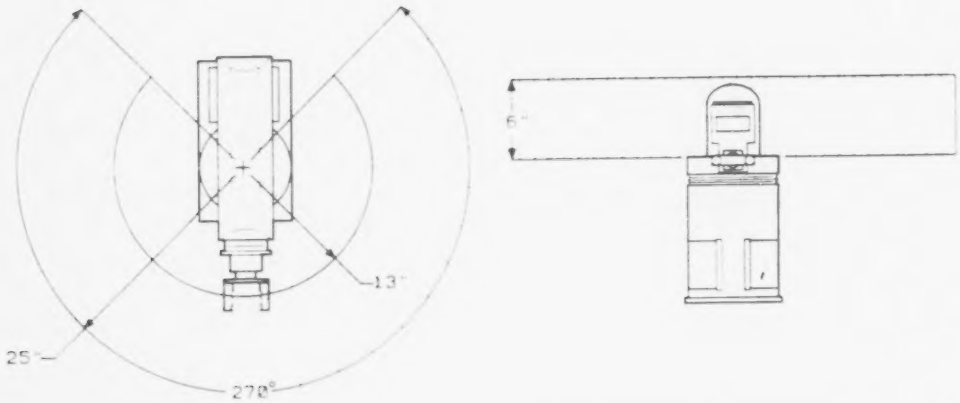
Answers to Assignment Sheets

Assignment Sheet 2



Answers to Assignment Sheets

Assignment Sheet 3



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Assignment Sheet 4

1. X axis, Reach
2. A axis, Roll
3. Z axis, Height
4. C axis, Swing or rotate
5. 5th degree of freedom

Nonservo Robot Operations
Unit 2

Answers to Written Test

1. a. 4
   b. 5
   c. 3
   d. 6
   e. 1

2. a. A
   b. C
   c. B

3. a. Cylindrical
   b. Spherical
   c. Rectangular
   d. Jointed (articulated)

4. a. Pitch
   b. Yaw
   c. Roll

5. a, c

6. c, d, e

7. a, c

8. Discussion should include:

   a. On-line programming
      (1) Applies to the continuous path class of robot.
      (2) The robot is programmed with less skill and time by leading the robot's manipulator through the desired path physically or by using a teach pendant.
      (3) In the majority of all cases the programmer teaches the robot on the production line (on-line).

   b. Off-line programming
      (1) Applies to the point-to-point robot.
      (2) This type of programming requires a great deal more skill and time.
      (3) Off-line programming simply means that the robot is programmed away from the production line (off-line).
      (4) Only about 2% of the current robot systems are programmed off-line.

Answers to Written Test

9. a, b, d, f

10. a. PLC
    b. Prior
    c. Safety
    d. Progression

11. a. Review the work envelope along with the entire work cell, and determine at which position of the robot would be most productive and safe for the home position.
    b. Determine what, if any, obstacles will need to be overcome during the operation of the robot.
    c. Consider the rotation of the robot ensuring that the robot's arm is retracted prior to that rotation eliminating the possibility of damaging the robot.
    d. Double check to make sure you understand the robot's left and right operating side.

12. a. Node
    b. Connecting
    c. Input/output
    d. Process
    e. Start/stop
    f. Decision

13. a. Overlooked
    b. Documentation
    c. Visually represent
    d. Event-driven
    e. Accidental

14. a. 2
    b. 1
    c. 3
    d. 4

15. b, d

16. a. 2 d. 7
    b. 8 e. 4
    c. 5 f. 1

17. a, c, d, e

Nonservo Robot Operations
Unit 2

Written Test

Name _____ Score _____

1. Match terms on the right with their correct definitions by writing the corresponding numbers on the blanks provided.

_____a.	A robot which does not provide the controller with constant positional feedback	1. Actuators
_____b.	Indicates the position number or name of robot joints	2. Event sequence programming
_____c.	The starting position of the robot and its manipulator	3. Home position
_____d.	The geometric drawing which displays the actual motion of the robot's manipulator	4. Nonservo robot
_____e.	Motors or transducers which use electrical, hydraulic, or pneumatic energy to move the robot	5. Positional data
		6. Robot arm geometry

2. Distinguish between the three classifications of robots according to their motion control by placing the following letters next to the correct description:

A — Continuous path
B — Pick-and-place
C — Point-to-point

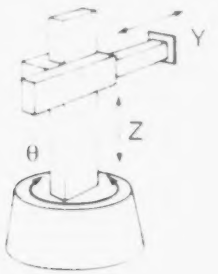
_____a. Programmed to travel any path as described: programmed by physically grabbing the robot's arm and leading it through the desired path: servo-controlled

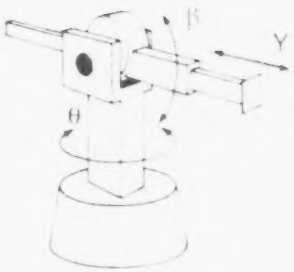
_____b. Most common servo-controlled robot: programmed to move from point to point within its work envelope

_____c. Designed to pick up parts at one location and place them at another: simplest and least expensive type: nonservo-controlled

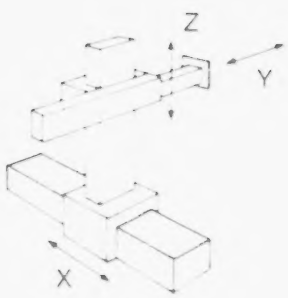
Written Test

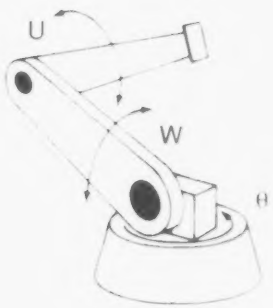
3. Identify the basic types of robot arm geometry below.





a. _____ b. _____





c. _____ d. _____

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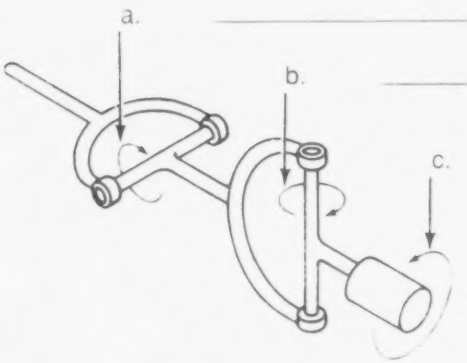
Written Test

4. Label the orientation axes of wrist rotation in the blanks provided below.



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5. Select true statements concerning the characteristics of fluid power sources for nonservo robots by writing an "X" on the blank before each true statement.

_____a. Fluid power sources consist of pneumatic and hydraulic actuators which are used to convert energy into mechanical energy.

_____b. Fluid power sources are used in approximately 20 percent of all robots because of their poor lift capabilities and cost efficiency.

_____c. Maintenance on nonservo robots is relatively low and can be accomplished in a limited amount of time.

6. Select from the following list the characteristics of hydraulic drive systems by placing an "X" next to the correct characteristics.

_____a. Use air under pressure to cause various actuators to perform various functions

_____b. Are limited to lifting only light objects

_____c. Are capable of operating the manipulator at moderate speeds

_____d. Are used in a large majority of robots

_____e. Are more expensive than pneumatic drives

Written Test

7. Select from the following list the characteristics of pneumatic drive systems by placing an "X" next to the correct characteristics.

   _____ a. Use air under pressure to cause various actuators to perform various functions

   _____ b. Are capable of moving heavy objects

   _____ c. Are capable of operating at high rates of speed

   _____ d. Are more expensive than hydraulic drives

8. Discuss the difference between on-line and off-line programming by writing a short summary about each on the blanks provided below.

   a. On-line Programming: _____

   _____

   _____

   _____

   _____

   _____

   b. Off-line Programming: _____

   _____

   _____

   _____

   _____

   _____

Written Test

9. Select true statements concerning basic robot programming by writing an "X" on the blanks before each true statement.

   _____a. The robot controller uses two basic programs: the control program and the user program.

   _____b. The basic operation of the robot is controlled by the user program.

   _____c. The control program is written by the operator to meet the needs of the robot's environment.

   _____d. The user program must also contain positional data which describe the axis movement of the robot.

   _____e. Geometric moves are defined by the control program indicating the movement of the robot's axes as they are made.

   _____f. Service requests must also be defined by the user's programming, thus defining any special action which is to occur once the manipulator has reached its desired position.

10. Complete statements concerning event sequence programming by writing the correct words in the spaces provided below.

    a. Event sequence programming is specific to _____ operations.

    b. Event sequence programming ensures that one operation of the program is completed _____ to another beginning.

    c. _____ of the robot and the operator is more defined when event sequence programming is used.

    d. Logical _____ of the entire robot's operation is better understood through the use of event sequence programming.

11. State the sequence of events used in determining the home position for the robot.

    a. _____

    _____

    _____

    b. _____

    _____

    _____

c. _____

_____

_____

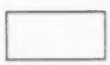
d. _____

_____

_____

12. Identify the basic flowchart symbols below by writing the correct term in the blanks provided.

a. _____ b. _____ c. _____



d. _____ e. _____ f. _____

13. Complete statements concerning the basic principles of robotic flowcharting by writing in the correct word or phrase in the blanks provided below.

a. Flowcharting is one of the most critical, yet _____, steps in developing a program for a robotic application.

b. Logical sequencing, as well as proper _____ within a flowchart, will aid the designer/programmer.

c. The flowchart should _____ how the program will achieve the sequence of operations.

d. A flowchart should show the use of _____ programming to ensure that one action triggers the next in the desired sequence of operations.

e. A flowchart should show how your program will be constructed to shut itself down when _____ operation of limit switches occurs.

14. Match PLC components on the right with their correct functions by writing the corresponding numbers on the blanks provided.

_____a.	A component that gathers signals from a process and sends information about the process on to a controller	1. Controller 2. Input module
_____b.	The brains of a PLC where logic solving and decision making are performed and appropriate signals are sent to an output module	3. Output module 4. Programmer
_____c.	A component that receives controller output and forwards signals on to real-world devices such as robot controllers	
_____d.	A device where a set of instructions stored in memory can be used to tell a controller how to manage a specific operation	

15. Select from the following list the characteristics of PLC programming of nonservo robots by placing an "X" next to the correct characteristics.

_____a. Make reprogramming job tasks more difficult

_____b. Enhance the robot's multi-tasking operations

_____c. Are very rare in the robotic environment

_____d. Can be programmed using ladder logic diagrams and minimal programming skills

_____e. Are designed to function only in sterile environments

Written Test

16. Match PLC programming terms on the right with their correct definitions by writing the corresponding numbers on the blanks provided.

_____a.	A basic statement in the PLC logic that directs a status bit to look for a condition where power in a circuit is OFF	1. Address 2. Examine off 3. Examine on 4. Hard-wired 5. Normally closed 6. Normally opened 7. Programmable logic controller (PLC) 8. User program
_____b.	A set of instructions which can be entered into processor memory at a local time and place by a programmer	
_____c.	A switch or contact which is closed and passing power when it is inactive, and open and not passing power when it is active	
_____d.	A microprocessor-based control system designed to respond to user input in executing a control objective	
_____e.	An electrical control design built around relays where components have to be physically wired to one another to complete electrical continuity	
_____f.	The numerical location of a particular status bit in the permanent memory of a PLC processor	

17. Select true statements concerning the verification and identification of input/output addresses by writing an "X" on the blank before each true statement.

_____a. It is vitally important to visually verify and identify the address to each limit and solenoid in order to control the sequence of motion of the robot's axes.

_____b. In general, not every robot will have a power diagram showing the position of each limit switch.

_____c. Input/output diagrams are also provided with robotic systems showing the input and output diagrams for that specific robot.

_____d. Manual testing of each solenoid and limit switches will allow the operator to see the full operation of each axis prior to programming.

_____e. A good understanding of the entire operation of the robot will enhance the programming and operation of that robot.

_____f. Covers should never be removed to test switches or solenoids.

_____g. Electrical power to the robot must remain <u>on</u> to test switches or solenoids.

*Permission to duplicate this test is granted.

Nonservo Robot Operations
Unit 2

Unit Evaluation Form

Student Name _____ Unit Rating _____

Assignment Sheet 1—Calculate the Lift Capabilities of the Mercury Robot Rating _____

Comments: _____

_____

Assignment Sheet 2—Develop a Flowchart for a Sequence of Operations Rating _____

Comments: _____

_____

Assignment Sheet 3—Draw a Work Envelope for the Mercury Robot Rating _____

Comments: _____

_____

Assignment Sheet 4—Locate Axes and Degrees of Freedom for the Mercury Robot Rating _____

Comments: _____

_____

Job Sheet 1—Identify Limit Switches, Solenoid Locations, and Addresses for the Mercury Robot Rating _____

Comments: _____

_____

Job Sheet 2—Enter a Program Using Event Sequencing Rating _____

Comments: _____

_____

Job Sheet 3—Enter a Program to Operate the Mercury Robot Using Output Reenergization Rating _____

Comments: _____

_____

Unit Evaluation Form

Job Sheet 4—Develop a Flowchart and Program for a Robotic Work Cell Application Rating _____

Comments: _____

_____

Written Test Scores

Pretest _____ Posttest _____ Other _____

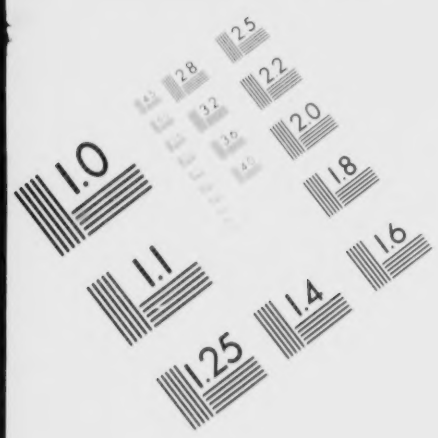
Other _____

_____

Teacher Signature _____ Date _____

Student Signature _____ Date _____

***Permission to duplicate this form is granted.**



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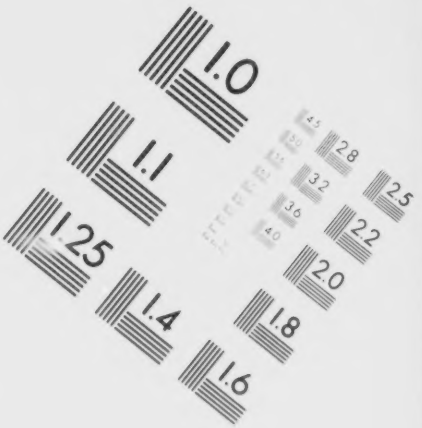

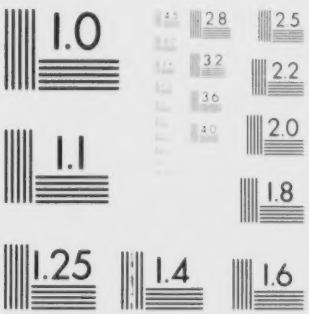

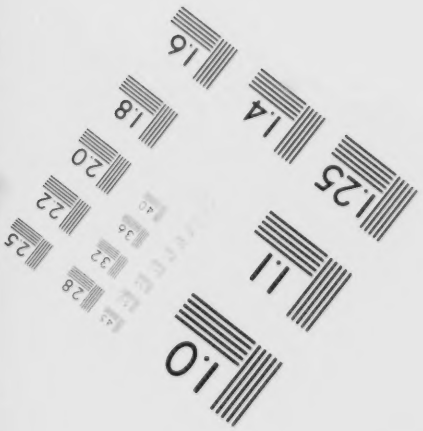

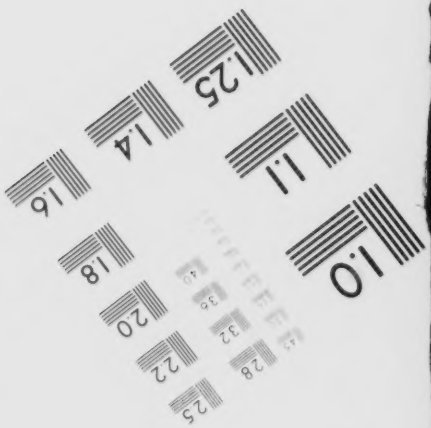

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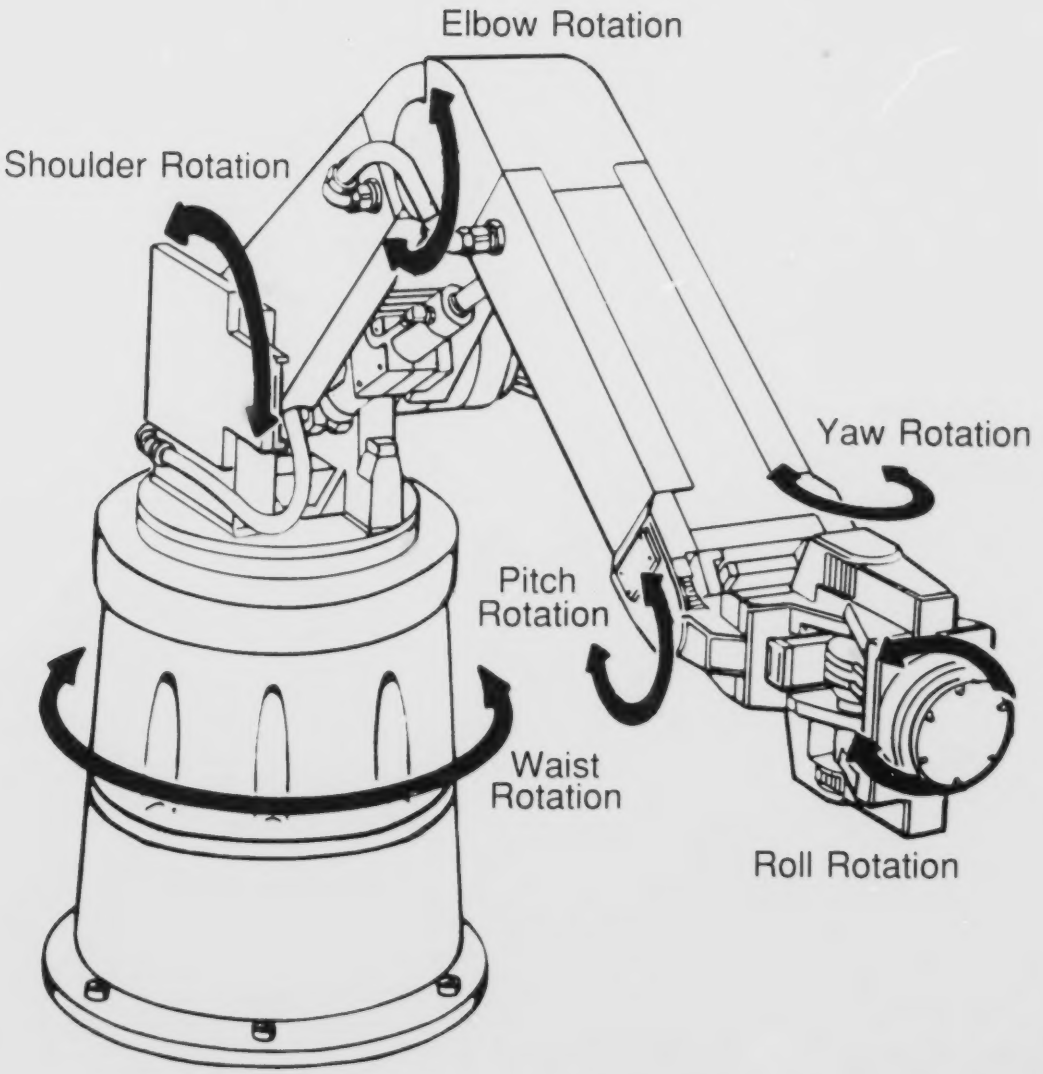
BY APPLIED IMAGE, INC.

Robot Arm and Wrist Rotations (Jointed)



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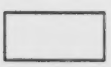
Basic Flowchart Symbols

Start/Stop

Input/Output

Decision



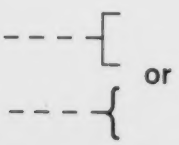
Process

Node

Flow

Connecting

Off-Page Connection



Annotation

Nonservo Robot Operations
Unit 2

Information Sheet

1. Terms and definitions

a. **Actuators** — Motors or transducers which use electrical, hydraulic, or pneumatic energy to move the robot

b. **Coordinates** — Set of numbers used in specifying the location of a point on a line, on a surface, or in space

Note: Different types of coordinates are used to specify the movement of the robot's manipulator.

c. **Event sequence programming** — The programming of a robot to ensure that one task or element of motion is completed prior to another starting

d. **Home position** — The starting position of the robot and its manipulator

e. **Nonservo robot** — A robot which does not provide the controller with constant positional feedback

Note: Positional feedback is usually provided at end of stroke. These units are usually hydraulic or pneumatic powered.

f. **Positional data** — Indicates the position number or name of robot joints

g. **Robot arm geometry** — The geometric drawing which displays the actual motion of the robot's manipulator

2. Classifications of robots according to their motion control

a. **Pick-and-place**

(1) Designed to pick up parts at one location and place them at another

(2) Simplest and least expensive type of robot

(3) Can be used in unloading conveyors or simple press loading/unloading operations

(4) Are nonservo-controlled

Information Sheet

b. **Point-to-point**

(1) Programmed to move from point to point within its work envelope, although not necessarily moving in a straight line between points

(2) Most common servo-controlled robot

(3) Used in simple machine loading/unloading applications as well as more complex applications such as spot welding, assembly, and palletizing operations

(4) Teach pendant generally used to program this type

Note: "Control Path" is a method added to the point-to-point robot which helps in ensuring that the robot will always travel in a straight line between two points.

c. **Continuous path**

(1) Programmed to travel any path as described (arc, circle, or straight line)

(2) Used for spray painting, arc welding, and many other operations which require constant control of the robot's manipulator path

(3) Programmed by physically grabbing the robot's arm and leading it through the desired path; speeds and path are recorded by the robot

(4) Are servo-controlled

Note: The primary difference between point-to-point and continuous path robots is the continuous path's ability to remember thousands of programmed points. Point-to-point robots are generally limited to only remembering several hundreds of points in its memory.

Information Sheet

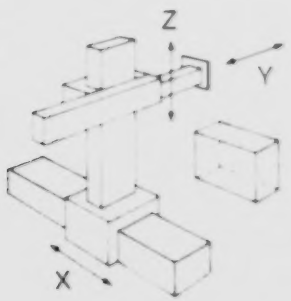
3. Basic types of robot arm geometry

Note: Each type of arm geometry denotes a specific work envelope as described in Unit 1.

a. Rectangular — Uses three axes of linear motion

Note: Rectangular arm geometry requires the simplest form of control since robot motion requires the operation of only one actuator per axis. This arm geometry is often found in overhead or gantry robots. Figure 1 indicates "3P;" this arm geometry consist of three (3) axes of prismatic (P) or linear motion.

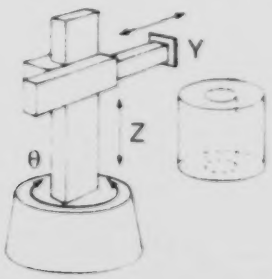
Figure 1—Rectangular geometry (Cartesian coordinates) 3P



b. Cylindrical — Uses two axes of linear motion and one axis of rotational motion

Note: This type of arm geometry is commonly used in machine tending, assembly, material handling, and palletizing operations. Figure 2 indicates "R2P:" this arm geometry consist of one rotational (R) and two linear (P) axes of motion. Sometimes R2P is written as RPP.

Figure 2—Cylindrical geometry (cylindrical coordinates) R2P



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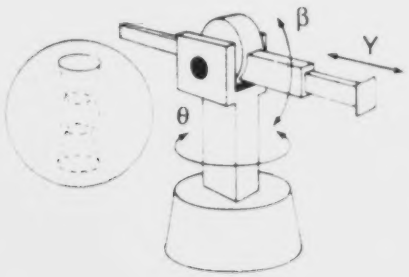
Information Sheet

c. Spherical — Uses two axes of rotational motion and one axis of linear motion.

Note: This is one of the first types of arm geometry used. However it is used very little today because of its lack of versatility. It is primarily used in material handling, machine tending, and spot welding. Figure 3 indicates "2RP" with two rotational (R) and one linear (P) axes of motion.

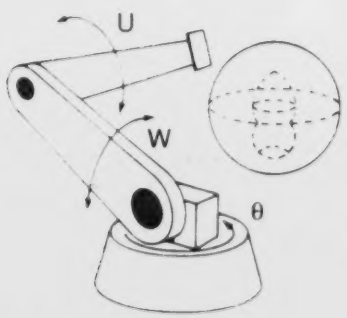
Figure 3—Spherical geometry (polar coordinates) 2RP



d. Jointed (articulated) — Uses three rotational axes

Note: Figure 4 shows "3R," three rotational axes.

Figure 4—Jointed geometry (revolute coordinates) 3R



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Information Sheet

4. Orientation axes of wrist rotation

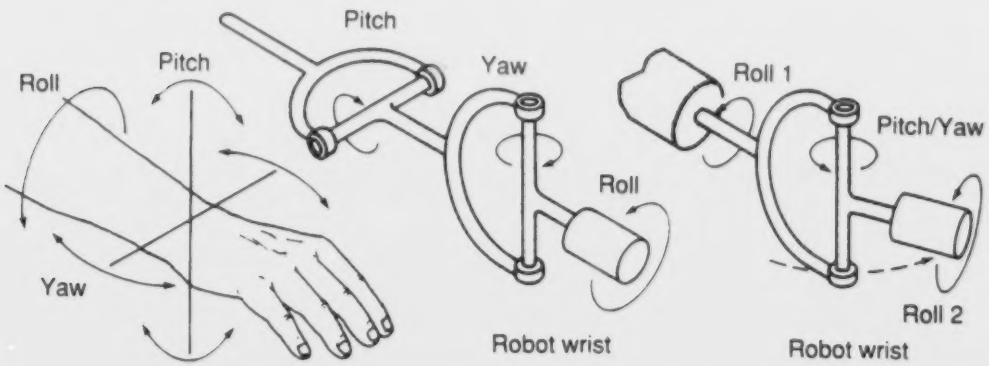
Note: In almost every case the manipulator carries a wrist assembly to orient its end-of-arm tooling (end effector).

a. **Yaw axis** — The horizontal rotation of the wrist, which can rotate between 90 degrees and 270 degrees.

b. **Pitch axis** — The vertical rotation of the wrist, which has an angular motion which ranges from a very small amount up to 270 degrees.

c. **Roll axis** — The capability of the wrist to turn 360 degrees about a longitudinal axis.

Figure 5



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Note: Figure 5 compares the movement of a robot wrist with that of the human wrist. Notice the similarities in the three joints and their movements.

5. Characteristics of fluid power sources for nonservo robots

a. Fluid power sources consist of pneumatic and hydraulic actuators which are used to convert energy into mechanical energy.

b. Fluid power sources are used in approximately 80 percent of all robots because of their lift capabilities and cost efficiency.

c. Maintenance on nonservo robots is relatively low and can be accomplished in a limited amount of time.

Information Sheet

6. Hydraulic drive systems

a. Use liquids (oils) under pressure to cause various actuators to perform various functions

b. Are capable of moving heavy objects

c. Are capable of operating the manipulator at moderate speeds

d. Can hold the manipulator motionless at desired positions

e. Some noise and fluid pollution can occur

f. Require little periodic maintenance

g. Are used in a large majority of robots

h. Are more expensive than pneumatic drives; however, they give greater lift capabilities

7. Pneumatic drive systems

a. Use air under pressure to cause various actuators to perform various functions

b. Are limited to lifting only light objects

c. Are capable of operating at high rates of speed

d. Are capable of losing air pressure

e. Are relatively inexpensive; less expensive than hydraulic drives

8. On-line and off-line programming

a. **On-line programming**

(1) Applies to the continuous path class of robot

(2) The robot is programmed with less skill and time by leading the robot's manipulator through the desired path physically or by using a teach pendant.

(3) In the majority of all cases the programmer teaches the robot on the production line (on-line).

Information Sheet

b. **Off-line programming**

(1) Applies to the point-to-point robot

(2) This type of programming requires a great deal more skill and time.

(3) Off-line programming simply means that the robot is programmed away from the production line (off-line).

(4) Only about 2% of the current robot systems are programmed off-line.

9. Basic robot programming

a. The robot controller uses two basic programs:

(1) Control or executive program

(2) User program

b. The control program is provided by the manufacturer and gives the controller the necessary routines for the PLC's basic operation.

c. The basic operation of the robot is controlled by the user program.

d. The user program must also contain positional data which describe the axis movement of the robot.

e. Geometric moves are defined by the user program indicating the movement of the robot's axes as they are made.

f. Service requests must also be defined by the user's programming, thus defining any special action which is to occur once the manipulator has reached its desired position.

g. Feed rate is the axis speed for reaching the desired position. This will vary according to the manufacturer's preprogrammed values.

Note: The speed at which an axis moves can be either the composite speed or the single-axis speed.

10. Event sequence programming

a. Event sequence programming is specific to PLC operations.

b. Event sequence programming ensures that one operation of the program is completed prior to another beginning.

c. Safety of the robot and the operator is more defined when event sequence programming is used.

d. Logical progression of the entire robot's operation is better understood through the use of event sequence programming.

Information Sheet

11. Sequence of events in determining the home position

a. Review the work envelope along with the entire work cell, and determine which position of the robot would be most productive and safe for the home position.

b. Determine what, if any, obstacles will need to be overcome during the operation of the robot.

c. Consider the rotation of the robot ensuring that the robot's arm is retracted prior to that rotation eliminating the possibility of damaging the robot.

d. Double check to make sure you understand the robot's left and right operating side.

Note: Your perspective is facing the front of the robot. The robot's left is your left; the robot's right is your right.

12. Basic flowchart symbols

a. **Start/stop**

(1) Identifies a start, stop, or point of interruption in the program

(2) Terminal symbol is represented by an **oval**.

Figure 6

Information Sheet

b. **Input/output**

(1) Identifies a control signal or input/output data

(2) Symbol is represented by a **parallelogram**.

Figure 7

c. **Decision**

(1) Indicates a point in the program where a decision will be made regarding input or output.

(2) Also may indicate a point in the program where a decision will be made from the input of a specific program.

(3) Symbol is represented by a **diamond**.

Figure 8

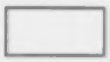
Information Sheet

d. **Process**

(1) Indicates that some type of process is taking place in the controller

(2) Symbol is indicated by a **rectangle**.

Figure 9



e. **Node**

(1) Is a certain point in a program where signals are coming into the program from different locations for processing purposes.

(2) Symbol is indicated by **arrows** and **circle** at point of intersection.

Figure 10

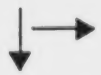
Information Sheet

f. **Flow**

(1) Indicates the direction of movement of signals

(2) Symbol consists of **arrows** connecting other symbols in the flowchart.

Figure 11



g. **Connecting**

(1) Used to tie several large flowcharts together

(2) Identified by a **circle**

Figure 12

Information Sheet

h. **Off-page connection**

(1) Used when a flowchart moves from one page to another

(2) Symbol is represented by a **polygon** in the shape of baseball's "home plate."

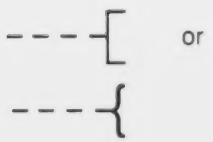
Figure 13

i. **Annotation**

(1) Used to express codes programmed by the user: similar to a legend on a map

(2) Symbol is represented by a **dashed line**. connected to a **straight or curved bracket**.

Figure 14



14. Principles of robotic flowcharting

a. Flowcharting is one of the most critical, yet often overlooked, steps in developing a program for a robotic application.

b. Logical sequencing, as well as proper documentation within a flowchart, will aid the designer/programmer.

c. The flowchart should visually represent how the program will achieve the sequence of operations.

Information Sheet

d. A flowchart should show the use of event-driven programming to ensure that one action triggers the next in the desired sequence of operations.

e. A flowchart should show how your program will be constructed to shut itself down when accidental operation of limit switches occurs.

Note: The flowchart in Figure 15 illustrates how a flowchart is designed to account for the cause and result of every event in the sequence of operations. This is one of the two common methods of flowcharting used for nonservo applications.

Figure 15

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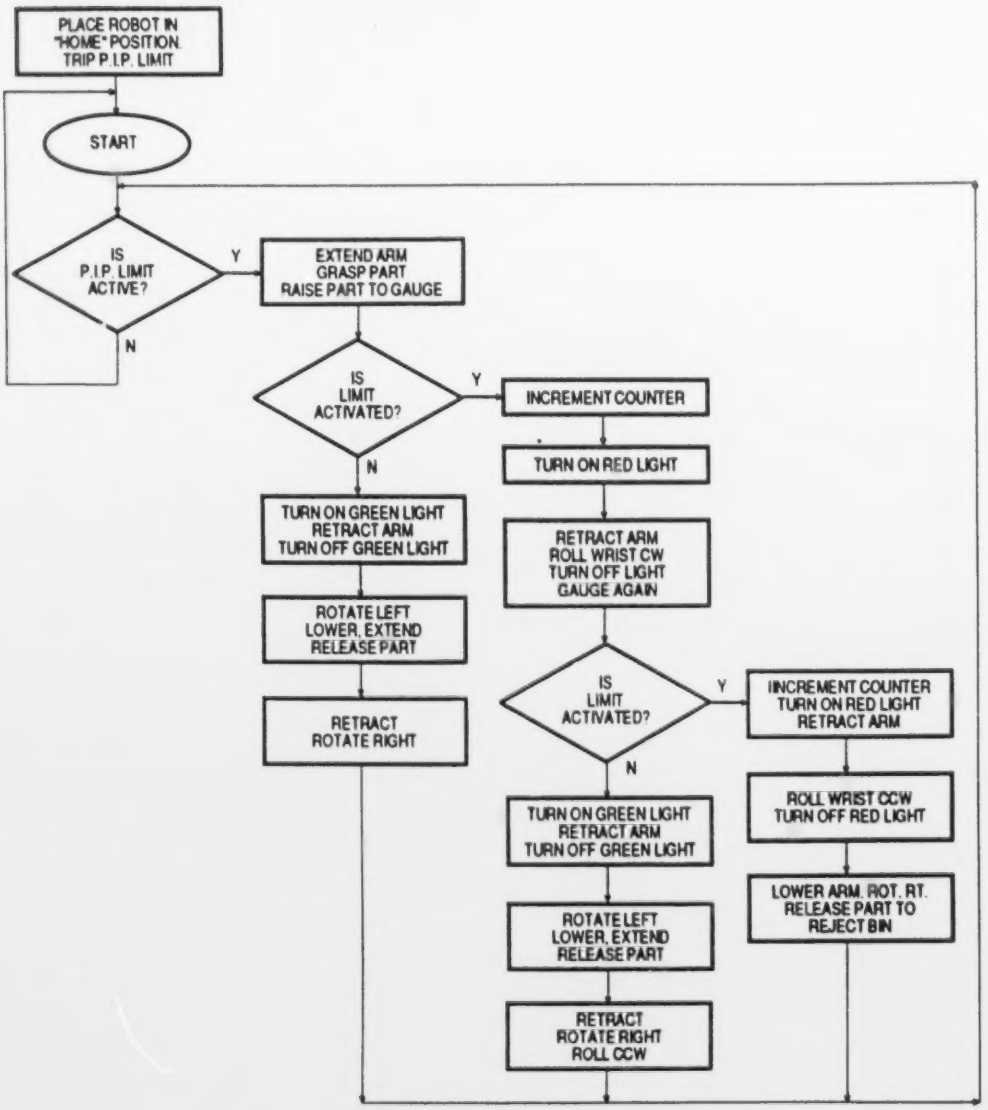
Information Sheet

f. The flowchart should also visually represent how the program will achieve the sequence of operations.

Note: The flowchart in Figure 16 illustrates how this type of application is shown.

Figure 16


PLACE ROBOT IN "HOME" POSITION. TRIP P.I.P. LIMIT
START
IS P.I.P. LIMIT ACTIVE?
Y
N
EXTEND ARM GRASP PART RAISE PART TO GAUGE
IS LIMIT ACTIVATED?
Y
N
INCREMENT COUNTER
TURN ON RED LIGHT
RETRACT ARM ROLL WRIST CW TURN OFF LIGHT GAUGE AGAIN
IS LIMIT ACTIVATED?
Y
N
INCREMENT COUNTER TURN ON RED LIGHT RETRACT ARM
ROLL WRIST CCW TURN OFF RED LIGHT
LOWER ARM, ROT. RT. RELEASE PART TO REJECT BIN
TURN ON GREEN LIGHT RETRACT ARM TURN OFF GREEN LIGHT
ROTATE LEFT LOWER, EXTEND RELEASE PART
RETRACT ROTATE RIGHT
TURN ON GREEN LIGHT RETRACT ARM TURN OFF GREEN LIGHT
ROTATE LEFT LOWER, EXTEND RELEASE PART
RETRACT ROTATE RIGHT ROLL CCW

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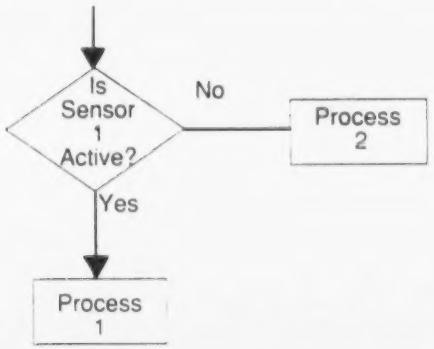
Information Sheet

g. Decision blocks can indicate an IF THEN, ELSE situation such as the presence of an input signal.

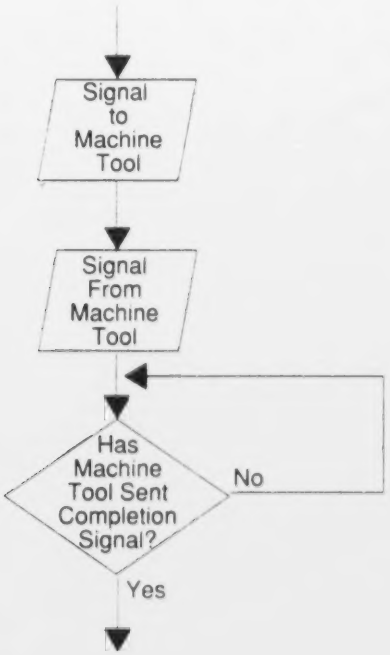
Note: In Figure 17, **IF** sensor number 1 is active, **THEN** process 1 will occur, **ELSE** process 2 will be the next operation.

Figure 17



h. Input/output boxes can be used to indicate operation to and from work cell peripherals.

Figure 18



Information Sheet

i. The process block provides information on geometry, velocity, positional data, and service requests.

(1) Geometry — Indicates the type of move required by the robot (linear, cylindrical, or rotational) or if there is simultaneous axes movement.

(2) Velocity — Indicates the speed at which the robot is moving. Using nonservo robots, this is slow to moderate; however, with servo robots this is indicated by the percent of full speed or in inches per minute.

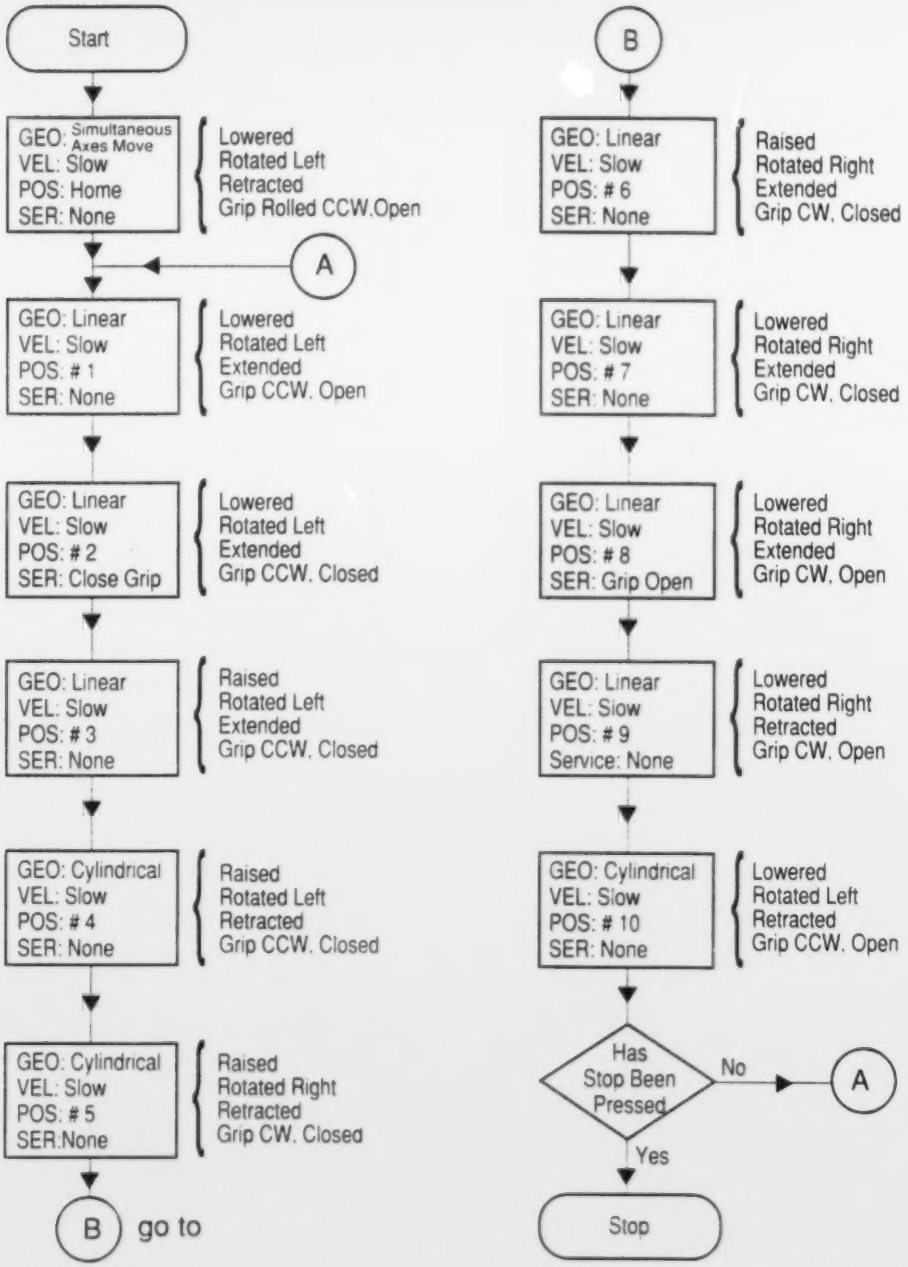
(3) Positional data — Indicates the position number or name. With nonservo robots this step is not essential due to the programming methods; however, servo robots store positional information based on a position number or name. In the servo robot, this step becomes vital.

(4) Service requests — Indicate the work or service to be performed at a particular position (grip a part, release part, insert screw, inspect part, etc.)

Note: Figure 19 shows an example of a flowchart for a nonservo robotic work cell application. The annotation is used to indicate the position of each axis or degree of freedom. This is the second of the two common methods of flowcharting used for nonservo robots.

Information Sheet

Figure 19



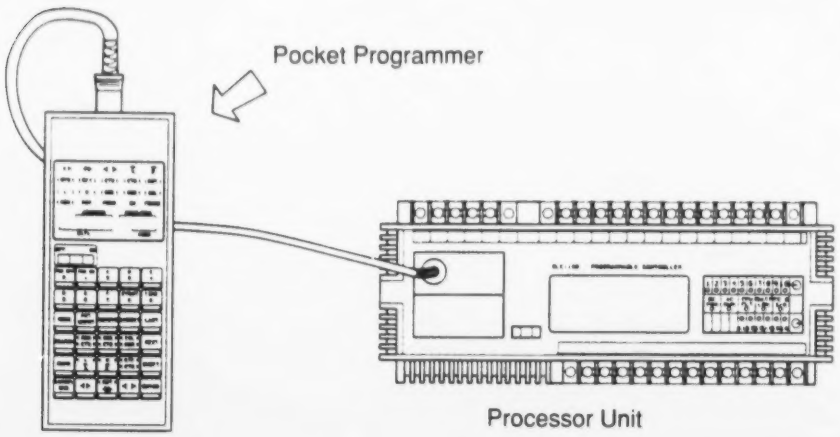
Information Sheet

14. PLC components and their functions

a. **Programmer** — A device where a set of instructions stored in memory can be used to tell a controller how to manage a specific operation

Note: Some PLCs use a hand-held programmer. Other PLCs are programmed using a standard computer keyboard.

Figure 20



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b. **Input module** — A component that gathers signals from a process and sends information about the process on to a controller

c. **Controller** — The brains of a PLC where logic solving and decision making are performed and appropriate signals are sent to an output module

d. **Output module** — A component that receives controller output and forwards signals on to real-world devices such as robot controllers

15. Characteristics of PLC programming of nonservo robots

a. Make reprogramming job tasks easier

b. Enhance the robot's multi-tasking operations

c. Are very prominent in the robotic environment

d. Can be programmed using ladder logic diagrams and minimal programming skills

e. Are designed to function in hostile environments including temperature extremes and areas contaminated with dust, dirt, vapors, and oils

f. Make discrete input-output easier

Information Sheet

16. PLC programming terms

a. **Address** — The numerical location of a particular status bit in the permanent memory of a PLC processor

b. **Examine OFF** — A basic statement in the PLC logic that directs a status bit to look for a condition where power in a circuit is OFF

c. **Examine ON** — A basic statement in the PLC logic that directs a status bit to look for a condition where power in a circuit is ON

d. **Hard-wired** — An electrical control design built around relays where components have to be physically wired to one another to complete electrical continuity

e. **Normally Closed (NC)** — A switch or contact which is closed and passing power when it is inactive, and open and not passing power when it is active

f. **Normally Open (NO)** — A switch or contact which is open and not passing power when it is inactive, and closed and passing power when it is active

g. **Programmable logic controller (PLC)** — A microprocessor-based control system designed to respond to user input in executing a control objective

h. **User program** — A set of instructions which can be entered into processor memory at a local time and place by a programmer

17. Verification and identification of input/output addresses

a. It is vitally important to visually verify and identify the address to each limit and solenoid in order to control the sequence of motion of the robot's axes.

b. In general, every robot will have a power diagram showing the position of each limit switch. This allows you to identify which limit switch input senses a particular actuator's position.

c. Input/output diagrams are also provided with robotic systems showing the input and output diagrams for that specific robot.

d. Manual testing of each solenoid and limit switch will allow the operator to see the full operation of each axis prior to programming.

e. A good understanding of the entire operation of the robot will enhance the programming and operation of that robot.

f. Some covers may need to be removed in order to test certain switches or solenoids.

g. Electrical power should be removed from the robot prior to testing any switches or solenoids.

Nonservo Robot Operations
Unit 2

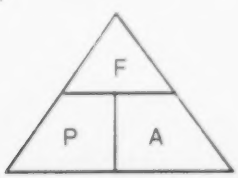
Student Supplement 1—Pascal's Law (Related Fluid Power Calculations)

1. Pascal's Law states. "Pressure set up in a confined body of fluids acts equally in all directions and always at right angles to the containing surfaces."

2. This relationship can be expressed mathematically as:

   Force = Pressure × Area
   (lbs) (psi) (in^2)

3. As with any three-part equation. Pascal's Law may be set up in triangular form as follows:



4. This will result in three equations:

$$F = PA$$

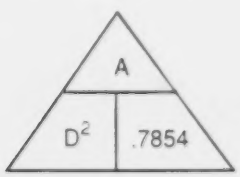
$$P = \frac{F}{A}$$

$$A = \frac{F}{P}$$

5. It is also necessary to calculate the square inch area of the piston base on bore size or piston diameter. The base equation to accomplish this is:

   Area = D^2 X .7854
   (in^2) (in.) (Constant)

6. This equation can also be set up in triangular form.



Student Supplement 1

7. This will result in two usable equations.

$$A = (D^2)\ (.7854)$$

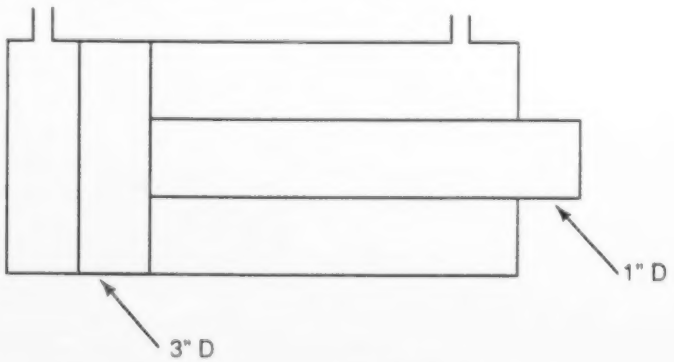
$$\frac{A}{.7854} = D^2 \text{ or}$$

$$D^2 = \frac{A}{.7854} \text{ or } D = \sqrt{\frac{A}{.7854}}$$

8. It will also be necessary to calculate the net area of the rod end of a cylinder in order to determine retraction force.

9. Net area is the area of the piston minus the area of the rod.

Example:



Piston Area
$A = (D^2)\ (.7854)$
$A = (9)\ (.7854)$
$A = 7.07\ in^2$

Rod Area
$A = (D^2)\ (.7854)$
$A = (1)\ (.7854)$
$A = .7854\ in^2$

Net Area
$7.07\ In^2$
$-\ .7854\ In^2$
$6.28\ In^2$

Nonservo Robot Operations
Unit 2

Assignment Sheet 1—Calculate the Lift Capabilities of the Mercury Robot

Name _____ Overall Rating _____

Evaluation criteria	Rating
Calculated lift correctly	_____
Calculated torque correctly	_____
Calculated reach forces correctly	_____

Directions: The forces that operate the axes of a nonservo robot are usually hydraulic or pneumatic. It is necessary to calculate the lift capabilities in order to determine the payload the robot is capable of handling.

1. Two actuators (cylinders) are used for axis 1 of the Mercury. The bore of each cylinder is 1.125″. Using the formulas to calculate area in Student Supplement 1, determine the combined lift area. Show your work.

2. Assuming that the operating pressure of the Mercury is 80 psig, and using the area calculated in the previous step, apply Pascal's Law and calculate the combined force. Show your work.

Assignment Sheet 1

3. The actual force or lift available to handle the payload is the result of the previous step, less the arm weight, the weight of the end effector, and losses due to friction. Frictional loss on the two actuators is minimal due to the low friction seal construction. The resistance will vary from .5 to 3.00 psi. Calculate the combined frictional loss using the worst case scenario of 3.00 psi. Show your work.

4. The total weight of the Mercury's arm and end effector is 66 pounds. With the total frictional loss from the vertical guide rods passing through the linear bearings, the weight is 68 pounds. With this information you now have compiled all the necessary figures to calculate the payload lift capabilities of the Mercury. Show your work.

The available force is _____.

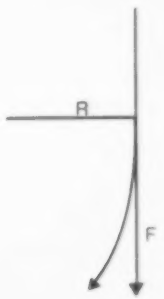
Note: The drop of the vertical lift assembly is not calculated due to the extreme gravity assist. Back pressure is necessary to prevent mechanical hammering.

Assignment Sheet 1

5. A rotary actuator is employed to swing the arm. The torque can be calculated with the formula *Torque (L) = Force (F) x Radius (R)*.

   Torque is usually expressed in inch-pounds. Torque is the product of a perpendicular driving force **F** times the length of the turning radius **R**.

   Figure 1



   Due to the ability of the arm to change length, the available torque will vary according to the turning radius **R** with the turning force remaining constant. The limited rotation rotary actuator used in the Mercury will require you to use displacement **D** instead of area in your calculation. The swept volume of the actuator is 270°. The displacement of the actuator is 4 cubic inches, and the operating pressure is 80 psig. Therefore:

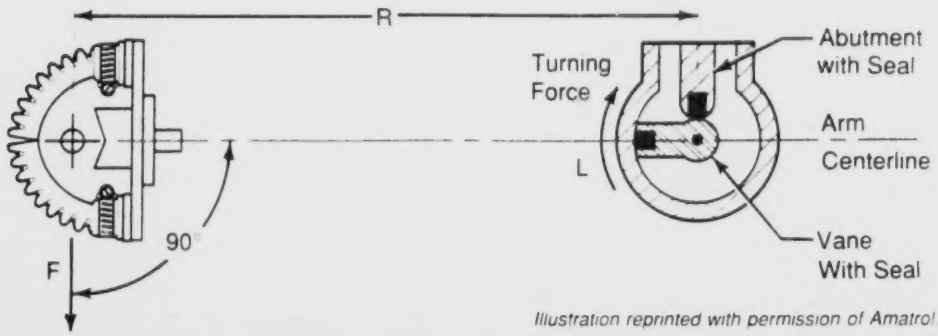
$$L = \frac{PSI \times D}{2\pi}$$

   Calculate the actuator torque using the above information. Show your work.

Assignment Sheet 1

6. The force available to turn depends on the position of the horizontal reach axis at midpoint of the load. That will be the assumed turning radius. The inside turning radius is 15 inches. The extreme radius is 27 inches. You must also consider the resisting torque that is caused by the seals and bearings. Figure 2 shows the areas of resisting torque.

Figure 2



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Using the equation **L = F/R**, you can now calculate the torque of the inside turning radius and the torque of the extreme turning radius. Show your work.

7. Based upon the previous calculations, answer the following questions:

		Yes	No
a.	The load turning force is greatest when the reach axis is extended.	_____	
b.	The fastest cycle time will occur when the axis is retracted.	_____	
c.	The program sequence should allow the robot to rotate with the axis extended whenever possible.	_____	

Assignment Sheet 1

8. The reach axis is operated by one linear actuator with a diameter of 1.125 inches. Loss due to friction on the rod seal is 3 psi. Apply the formulas for area and Pascal's Law to calculate the reach force, assuming a pressure of 80 psi. Show your work.

9. The retraction force of the reach axis must also be calculated. This will require you to subtract the area of the actuator's rod from the total area of the cylinder and apply Pascal's Law again based on the new figure. You must also consider the friction losses again. The diameter of the rod is .375 inches. Show your work.

Nonservo Robot Operations
Unit 2

Assignment Sheet 2—Develop a Flowchart for a Sequence of Operation

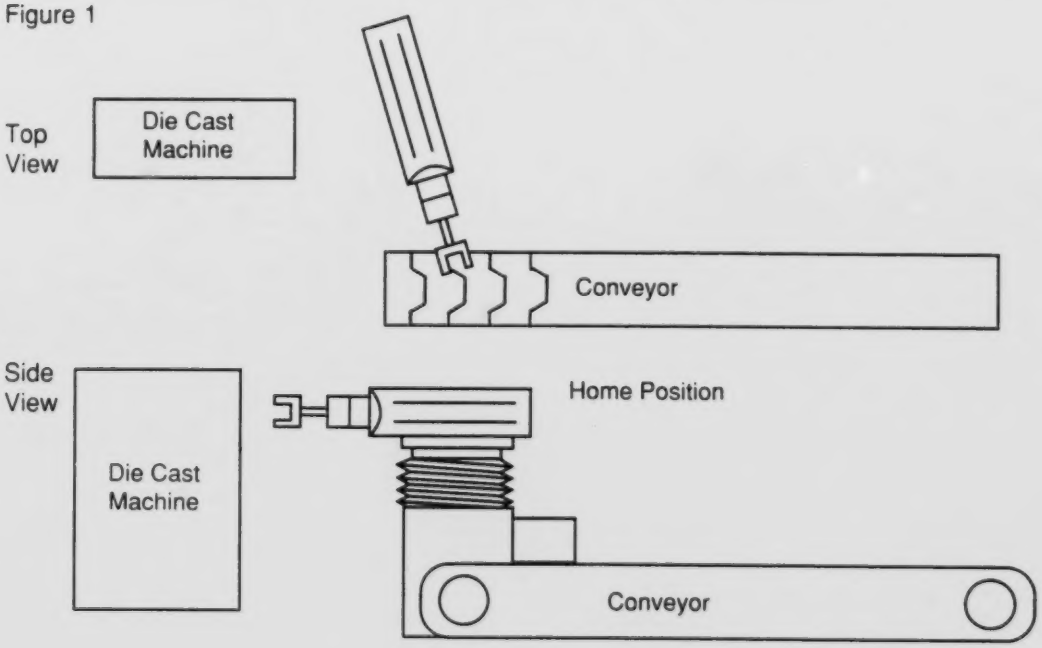
Name _____ Overall Rating _____

Evaluation criteria	Rating
Identified proper sequence	_____
Used proper flowchart symbols	_____

Directions: Using the scenario below, identify the proper sequence of operation, and develop a flowchart for the robotic application on grid paper provided by your instructor.

Scenario:
The Mercury robot has been chosen to perform a material handling operation. The parts being handled are first removed from a diecast machine. This will entail reaching into the machine to retrieve the parts. The part is then rotated 100 degrees and placed on a conveyor. See Figure 1 to determine the proper sequence of operations.

Figure 1



Nonservo Robot Operations
Unit 2

Assignment Sheet 3—Draw the Work Envelope of the Mercury Robot

Name _____ Overall Rating _____

Evaluation criteria	Rating
Side view drawn and dimensioned correctly	_____
Top view drawn and dimensioned correctly	_____

Directions: As with most nonservo robots, the work envelope of the Mercury robot is adjustable. It is extremely important, however, to never assume its adjusted size. The robot can reach its maximum limitations at any time. Below you will find drawings of the Mercury. Using the information found in the statements below, draw the work envelope of the robot.

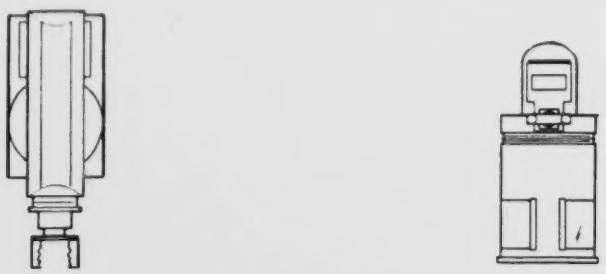
A. The maximum amount the Mercury can raise is 6 inches.

B. The inside radius measured from the center point of the robot is 13 inches.

C. The outside radius measured from the center point is 25 inches.

D. The maximum swing of the arm is 270 degrees.

Figure 1



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Nonservo Robot Operations
Unit 2

Assignment Sheet 4—Locate Axes and Degrees of Freedom of the Mercury Robot

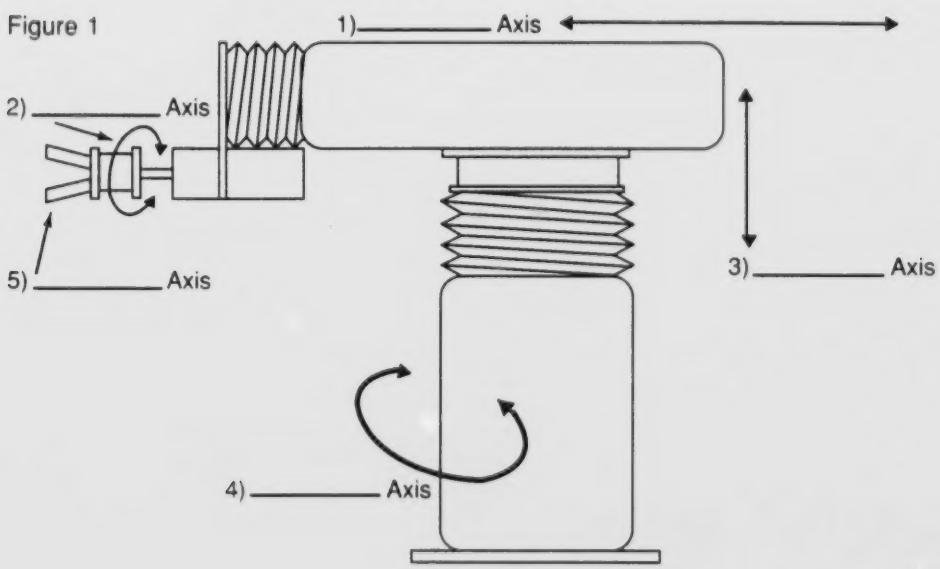
Name _____ Overall Rating _____

Evaluation criteria	Rating
Located the 4 axes	_____
Located the 5 degrees of freedom	_____

Directions: The Mercury pneumatic nonservo robot is a 4 axis cylindrical coordinate robot. Including the end effector (gripper), the robot has 5 degrees of freedom. Since the gripper is a type of end-of-arm tooling and can be exchanged for other end-of-arm tools, it is not a permanent part of the robot. It is, therefore, considered to be a degree of freedom but is not considered to be an axis. Using Figure 1, label the axes of the Mercury as well as the degrees of freedom.

Arm Height	(Vertical Body Axis	**Z**)
Arm Rotate	(Rotational Body Axis	**C**)
Arm Reach	(Horizontal Body Axis	**X**)
Wrist Roll	(Extreme Rotation Axis	**A**)

Figure 1



Nonservo Robot Operations
Unit 2

Job Sheet 1—Identify Limit Switches, Solenoid Locations, and Addresses for the Mercury Robot

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Found location of all limit switches	_____
Identified addresses of limit switches and solenoids correctly	_____

Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and rate your performance using the evaluation criteria.

A. Tools and materials

Mercury Robot
Allen Bradley SLC100 PLC
Programming device (hand-held programmer or personal computer and ladder diagram software)
Pneumatic power supply

B. Procedure

☐ 1. Disconnect the Mercury from all electrical power cables and remove all covers.

☐ 2. Operate each axis by hand.

a. To do this, operate the overrides located on the solenoids.

b. Use the power diagram (Figure 1) to assist in locating the proper solenoid.

c. When operating the axis, notice which LED on the input section of the programmable controller lights up.

d. Write this address and the name of the limit switch in the blanks on Figure 2.

Job Sheet 1

e. Locate the switches and their addresses in the following order:

(1) Arm raised

(2) Arm lowered

(3) Arm rotated right (facing the robot)

(4) Arm rotated left (facing the robot)

(5) Arm extended

(6) Arm retracted

(7) Wrist rolled clockwise (facing the robot)

(8) Wrist rolled counterclockwise (facing the robot)

Job Sheet 1

Figure 1—Mercury Robot Power Diagram

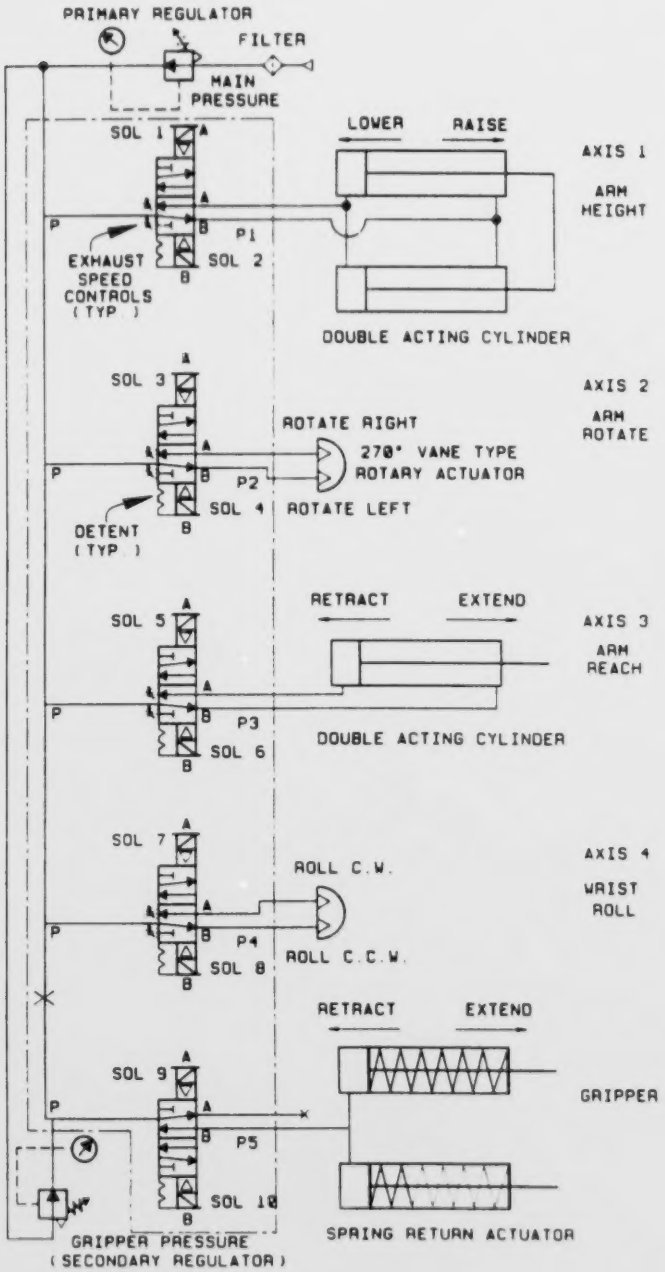
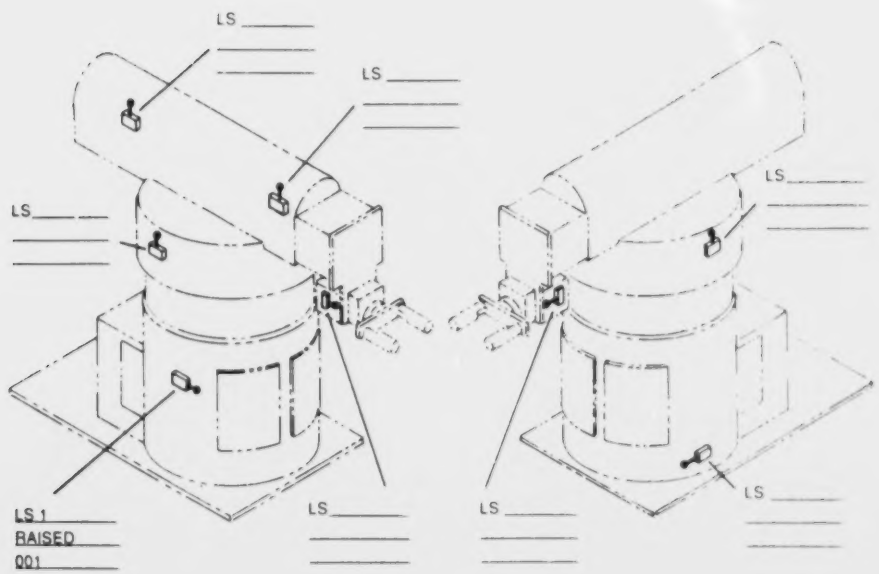


Illustration reprinted with permission of Amatrol, Inc.

Job Sheet 1

Figure 2—Identification of limit switches



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☐ 3. Using the manual overrides on the solenoids, set the axes of the robot to the following position:

a. Arm lowered

b. Arm rotated left

c. Arm retracted

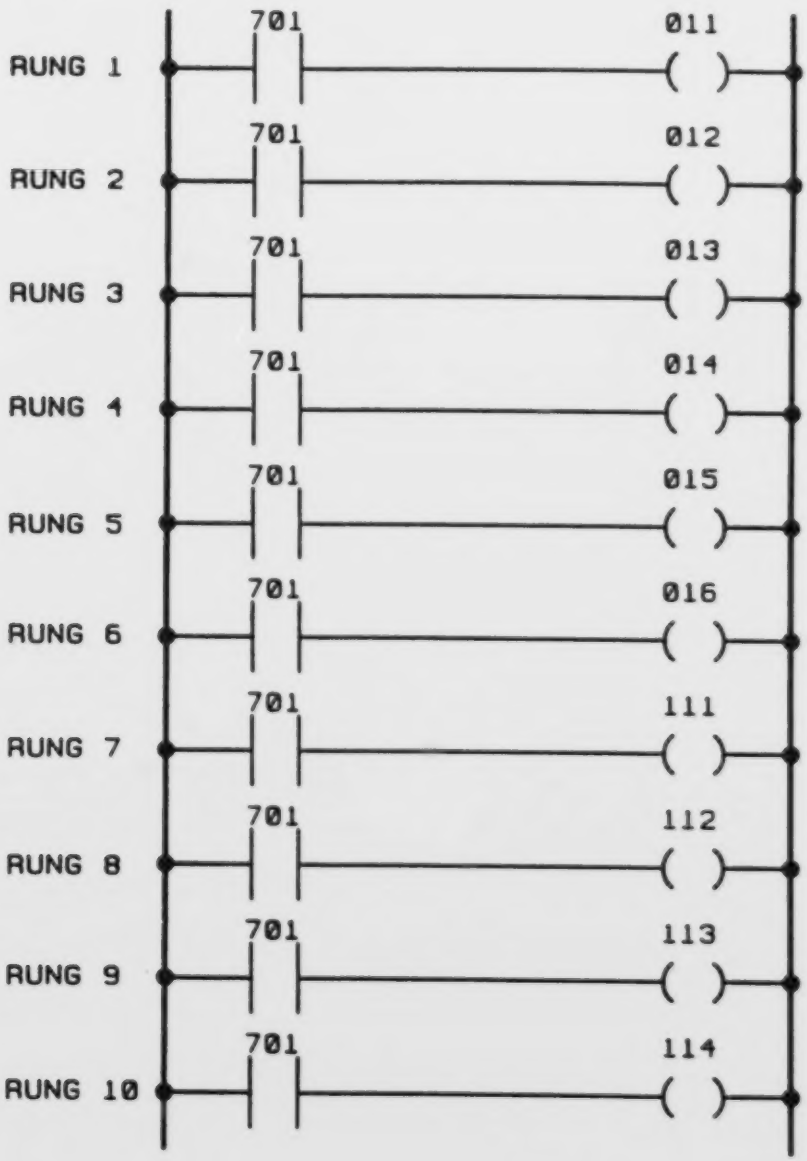
d. Wrist rolled CCW

e. Gripper closed

Job Sheet 1

☐ 4. Clear the memory of the PLC and enter the following program into memory:

Figure 3



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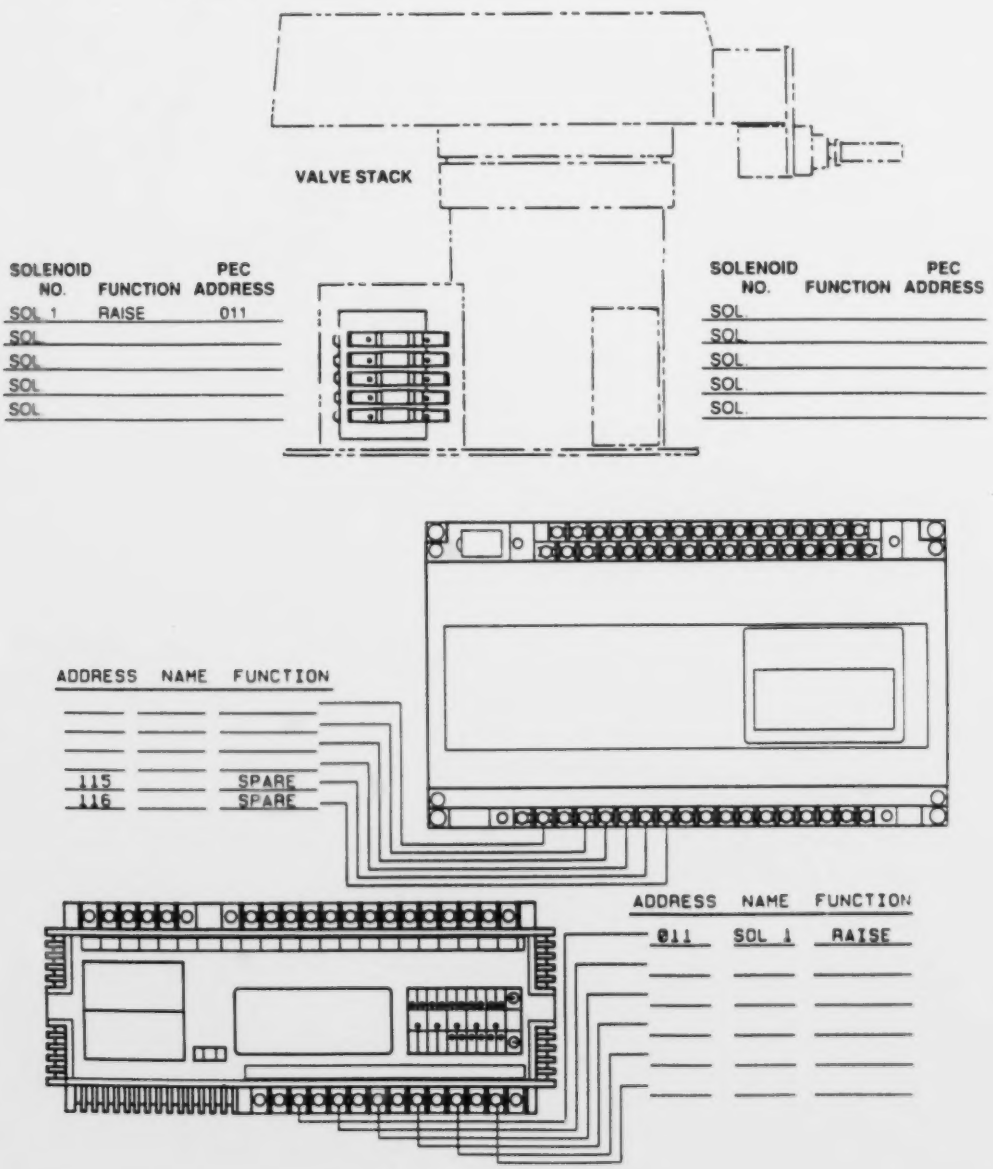
Job Sheet 1

☐ 5. Enter the run mode and force each output while observing which indicator on the solenoids lights up. Record the results on Figure 4 below.

Figure 4



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Job Sheet 1

☐ 6. When you have identified the locations of all inputs and outputs, notify your instructor.

☐ 7. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

Evaluator's comments: _____

_____

_____

Nonservo Robot Operations
Unit 2

Job Sheet 2—Enter a Program Using Event Sequencing

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Entered event sequence program correctly	_____
Executed first program correctly	_____
Entered event sequence program with gripper control correctly	_____
Executed second program correctly	_____

Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and rate your performance using the evaluation criteria.

A. Tools and materials

Mercury Robot
Allen Bradley SLC100 PLC
Programming device
Pneumatic power supply

Job Sheet 2

B. Procedure

☐ 1. Study the example of event sequence programming in Figure 1. Be careful to follow the correct sequence of events.

Figure 1

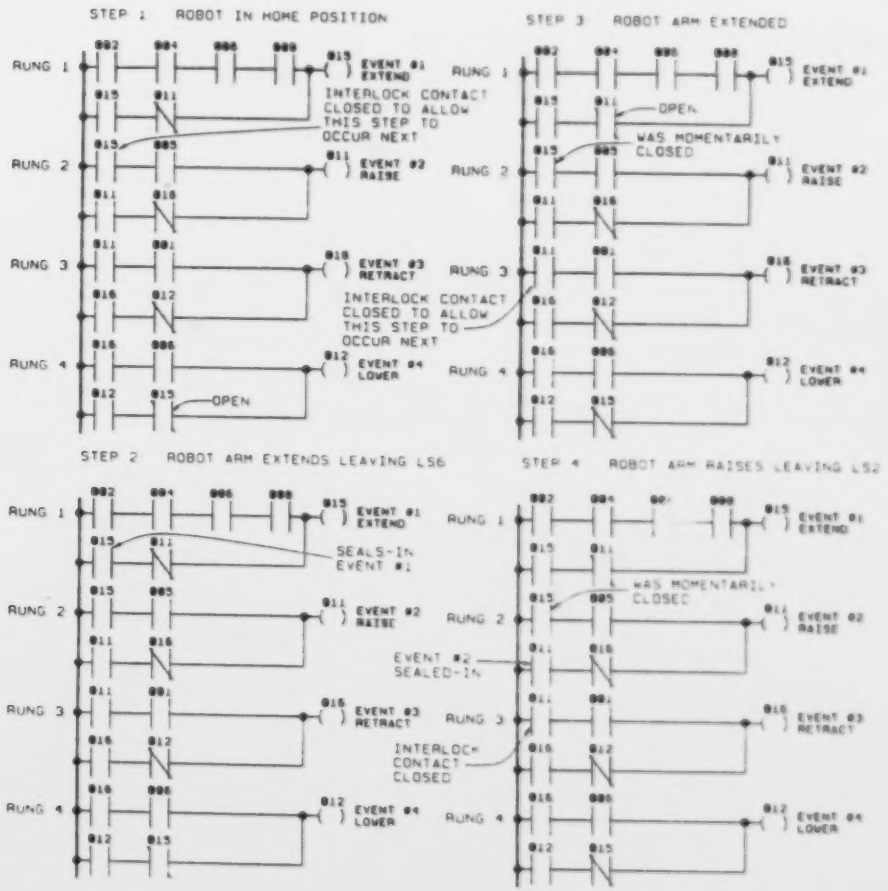


Illustration reprinted with permission of Amatrol, Inc.

Job Sheet 2

☐ 2. Clear the memory of the PLC and enter the program memory.

☐ 3. Set the robot in the following position:

a. Retracted

b. Lowered

c. Rotated right

d. Gripper CCW

e. Gripper open

☐ 4. Put the PLC into the run mode and observe the sequence of events. If the robot operates in the following manner, your program is entered correctly.

a. Arm extends

b. Arm raises

c. Arm retracts

d. Arm lowers

☐ 5. Debug your program if necessary.

Job Sheet 2

☐ 6. When the Mercury robot is performing an operation such as material handling, it is necessary to allow time for the robot's gripper to close before the robot moves to the next step in the event sequence program. Clear the memory of the PLC and enter the following program:

Figure 2

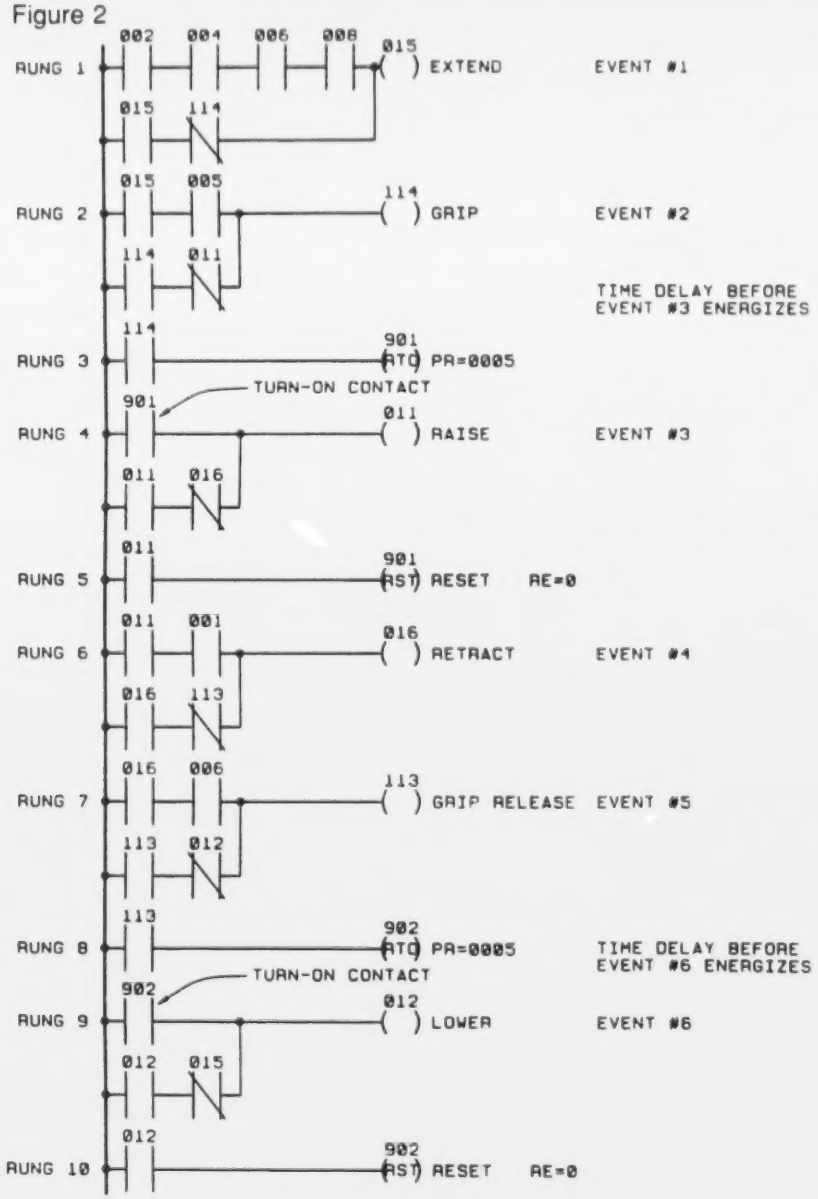


Illustration reprinted with permission of Amatrol, Inc.

Job Sheet 2

☐ 7. Set the robot in the following position:

a. Retracted

b. Lowered

c. Rotated right

d. Gripper CCW

e. Gripper open

☐ 8. Put the PLC in the run mode and observe the sequence of events. If the sequence is as follows, your program is correct.

a. Extend

b. Grip

c. .5 second delay

d. Raise

e. Retract

f. Grip release

g. .5 second delay

h. Lower

☐ 9. Debug your program if necessary.

☐ 10. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

Evaluator's comments: _____

_____

_____

Nonservo Robot Operations
Unit 2

Job Sheet 3—Enter a Program to Operate the Mercury Robot Using Output Reenergization

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Entered program correctly	_____
Executed program correctly	_____
Output operated successfully when reenergized	_____

Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and rate your performance using the evaluation criteria.

A. Tools and materials

Mercury Robot
Allen Bradley SLC100 PLC
Programming device
Pneumatic power supply

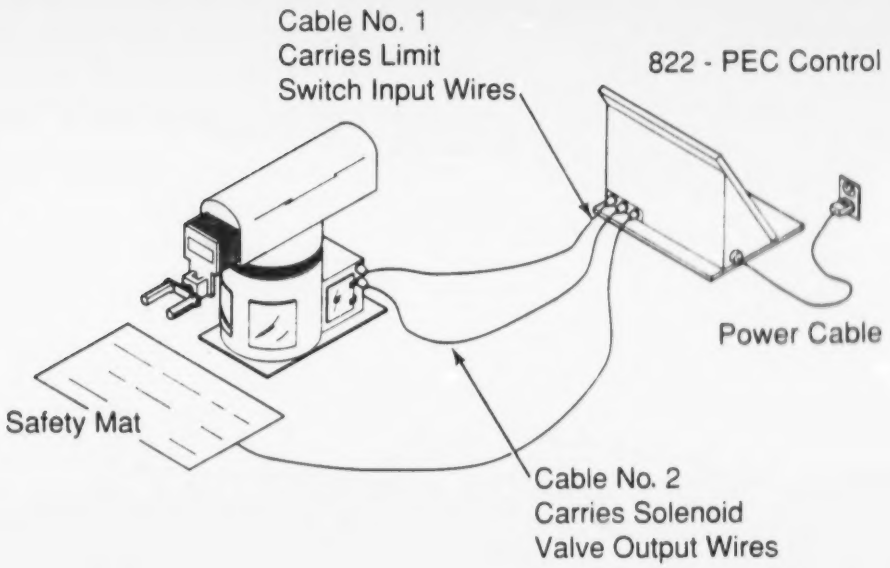
B. Procedure

Note: As you continue to program nonservo robots, you will encounter situations that require the manipulator to repeat a position or energize the same output repeatedly. Since a PLC will not operate properly if an output is used more than once, a method was devised to allow output reenergization.

☐ 1. Study Figure 1 taking note of the method used to operate the extend and retract axes more than once.

Job Sheet 3

Figure 1—Mercury Robot Setup with Controller and Mats



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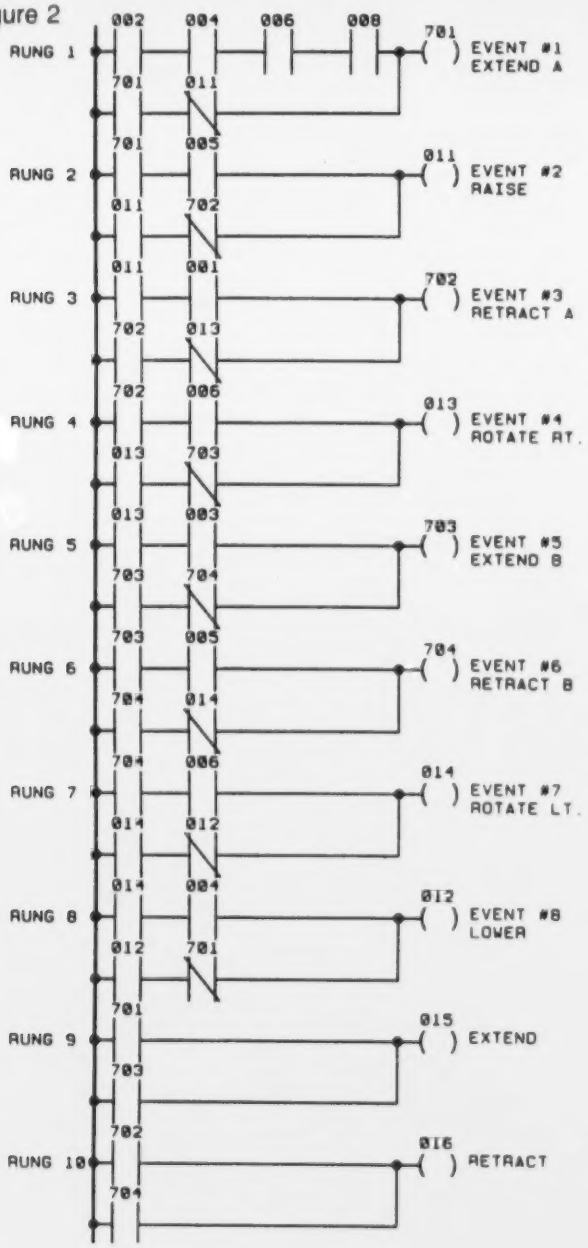
Job Sheet 3

☐ 2. Clear the memory of the PLC.

☐ 3. Enter the following program into the PLC's memory:

Figure 2



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Job Sheet 3

- ☐ 4. Test your program.
- ☐ 5. Debug your program if necessary.
- ☐ 6. Upon completion, have your instructor check your work.
- ☐ 7. Turn off all equipment.
- ☐ 8. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

Evaluator's comments: _____

_____

_____

Nonservo Robot Operations
Unit 2

Job Sheet 4—Develop a Flowchart and Program for a Robotic Work Cell Application

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Developed program using event sequence method	_____
Executed program correctly	_____

Instructions: When you are ready to perform this task, ask your instructor to observe the procedure and rate your performance using the evaluation criteria.

A. Tools and materials

Mercury Robot
Allen Bradley SLC100 PLC
Programming device
Pneumatic power supply
Gridded paper

B. Procedure

☐ 1. Select either Scenario 1 or Scenario 2 (Part C of this job sheet).

☐ 2. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence. Draw your flowchart on gridded paper.

☐ 3. Using your flowchart. develop an event sequence program to operate the Mercury Robot.

☐ 4. Enter your program using your programming device.

Job Sheet 4

- ☐ 5. Test your program.
- ☐ 6. Debug your program if necessary.
- ☐ 7. Upon completion, have your instructor check your work.
- ☐ 8. Turn off all equipment.
- ☐ 9. Check in equipment and materials and clean area, or prepare for next job sheet as directed by your instructor.

Evaluator's comments: _____

_____

_____

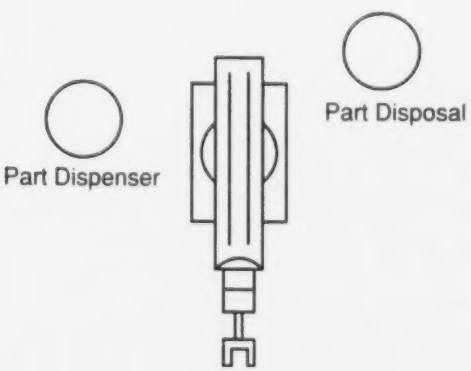
C. *Scenarios:*

Scenario 1: *As a technician for Mega Manufacturing, you are assigned the task of set up, programming, and documentation of a pick-and-place operation to be performed by the Mercury Pneumatic Manipulator. This will entail the repositioning of the hard stops, as well as determination of the home position and the sequence of operation. The **X** axis should be limited to 5.25 inches, and the **Z** axis should be limited to 3.00 inches. After looking at the work cell, determine the proper sequence of operation based on the work cell requirements and physical obstructions.*

Note: The scenario will differ depending on the equipment available in your robotics lab. See your instructor for the specifics of the work cell.

Figure 1

Top



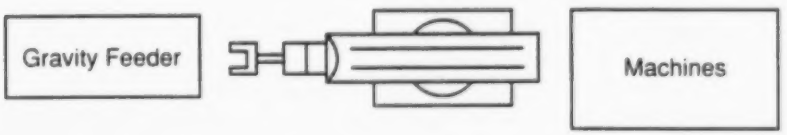
Job Sheet 4

Scenario 2: *Mega Manufacturing has added a process that will use the Mercury robot to tend two machine tools. The robot will retrieve the raw materials from a gravity feeder and place them into the two machines. One machine is located above the other. The Mercury can load both machines due to its 6 inch* ***Z*** *axis. Check the work cell in Figure 2 for any specifics that must be observed.*

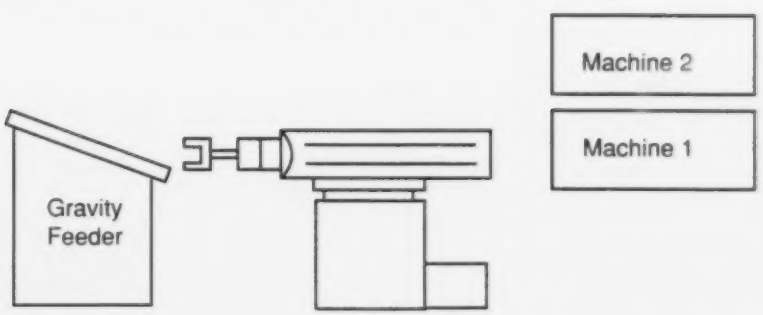
Note: The scenario will differ depending on the equipment available in your robotics lab. See your instructor for the specifics of the work cell.

Figure 2

Top View



Side View



Servo Robot Operations
Unit 3

Objective Sheet

Unit Objective

After completing this unit, the student should be able to explain the basic operations, motion, and programming features of a servo robot. The student should demonstrate these competencies by completing the assignment sheets and job sheets and by scoring a minimum of 85 percent on the written test.

Specific Objectives

After completing this unit, the student should be able to:

1. Match terms related to servo robot operations with the correct definitions.
2. Describe the three types of robotic controllers according to their technology level.
3. Select true statements concerning robotic controllers.
4. Identify path characteristics of robot motion control.
5. Distinguish between the types of axis control when teaching a robot.
6. Distinguish between the types of loop control.
7. Differentiate between open and closed loop control systems.
8. List advantages of feedback on robotic operations.
9. Match components of servo system control with their correct definitions.
10. Select true statements concerning stepper motor control.
11. Identify the major components of a teach pendant.
12. Match components of a teach pendant with their functions.
13. Match critical specifications of a robotic system with their descriptions.
14. Select true statements concerning servo controlled robots.
15. Differentiate between applications for closed loop control and open loop control.

Objective Sheet

16. Determine critical specifications using a robot manufacturer's specification sheet. (Assignment Sheet 1)

17. Determine meanings of various commands using the *ACL Reference Guide*. (Assignment Sheet 2)

18. Define various commands using the *ACL Reference Guide*. (Assignment Sheet 3)

19. Explain the sequence of operation of a given program using the *ACL Reference Guide*. (Assignment Sheet 4)

20. Design a flowchart for a robotic application. (Assignment Sheet 5)

21. Move and teach a robot using the teach pendant. (Job Sheet 1)

22. Develop a flowchart and program for a robotic work cell application. (Job Sheet 2)

Servo Robot Operations
Unit 3

Suggested Activities

Instructional Plan

Preparation

1. Read the unit carefully and plan for instruction.
2. Review Teaching Suggestions section that follows. Plan for classroom activities.
3. Plan for students with special needs.
4. Make a transparency from the transparency master included with this unit. This appears in the teacher edition only and is designed to be used with the following objective:

   TM 1—Major Components of a Teach Pendant (Objective 11)

5. Obtain films, videotapes, and other resources to supplement instruction of this unit. See ordering information in the Suggested Supplemental Resources section that follows.
6. Develop teaching plan. Adjust for different learning styles.
7. Review "Instructions for Evaluating Student Performance," which follows the resources in this section of the unit. Make copies of Unit Evaluation Form, which follows the written test section.

Delivery and Application

8. Provide students with unit of instruction.
9. Discuss unit and specific objectives.
10. Discuss information sheet. Implement teaching plan to localize, supplement, and personalize the unit. Reinforce basic academic and workplace skills when applicable.
11. Discuss the assignment sheets. Review criteria for evaluation of these activities.
12. Discuss and demonstrate the job sheets. Make sure all required tools, equipment, and supplies are available. Review criteria for evaluation of these activities.

Suggested Activities

Evaluation

13. Discuss the use of the Unit Evaluation Form with students. Discuss the rating scale that will be used for student evaluation.

14. Make copies of the written test. Add or modify test items as needed.

15. Give written test.

16. Compile assignment sheet ratings, job sheet ratings, and written test scores on the Unit Evaluation Form. Include any additional assignments.

17. Reteach and retest as required.

Teaching Suggestions

Note: Skill areas appearing in boldface type in the Teaching Suggestions refer to the academic and workplace skills identified by the American Society for Training and Development (ASTD) and the U.S. Department of Labor. These have been adapted by MAVCC.

1. To introduce this unit, display an example of a servo robot. Remove the housing covers exposing the axis drives. Hands-on experience will increase **tactile learning**.

2. To develop interest use a bulletin board headed "Components of a Servo Robot." Post pictures of the various types of servo robots and their components. Include some of the newer industrial robots.

3. Many robot manufacturers have short videos on their robots. Obtain sample videos and show to your class.

4. When covering objective 4, discuss the different types of motion control. Have the students discuss their advantages and disadvantages. Discussion can reinforce **creative thinking, critical thinking skills**, and **communication skills**.

5. Tour a nearby industry that uses servo robotics. This gives the students a chance to see how the robots interact in a full scale environment. **Communication skills** are used as students listen to and question the company guide. This may also help students see new **career** opportunities.

6. Have a flow chart design contest for a specific servo robot application. This could be a group or individual activity. Winners could be selected by the class, or you could form a panel of judges from the class. This contest reinforces **creative thinking skills, problem solving skills, self-esteem**, and **motivation**.

Suggested Activities

7. Provide gridded paper and flow chart symbol templates for students to use in the assignment and job sheets requiring them to draw flowcharts.

8. The Scorbot®-ER V robot was used as the basis for the assignment and job sheets in this unit. The laboratory manuals covering the Scorbot®-ER V robot are available from Eshed Robotec Inc. Refer to the "Suggested Supplemental Resources" that follow for ordering information. If you plan to use another robot in your course, you will need to write substitute assignment and job sheets that cover similar tasks.

9. Additional suggestions for Assignment Sheets 1 and 2—Divide the class in small groups and give each group a portion of the Assignment Sheet to complete during that period. Allow the students in each group to share their findings with the entire class. This reinforces **communication skills** and **teamwork**.

10. At the conclusion of this unit, ask students to write two short paragraphs about what they have found most interesting about servo robots. This reinforces their **writing foundation skills**.

References Used in Developing This Unit

1. Malcolm, Douglas R., Jr. *Robotics: An Introduction.* Boston: Breton Publishers, 1985.

2. Rehg, James. *Introduction to Robotics.* Barrington, IL: TPC Training Systems/ Technical Publishing, 1985.

3. Rehg, James. *Introduction To Robotics: A Systems Approach.* Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985.

Suggested Supplemental Resources

1. *Scorbot®-ER V User's Manual*, 2nd edition. Copyright 1991.

2. *ACL (Advanced Control Language) Reference Guide*, 3rd edition.

The Scorbot® manual and ACL guide are available from:

Eshed Robotec Inc.
445 Wall Street
Princeton, NJ 08540
Phone 609-683-4884

Suggested Activities

Instructions For Evaluating Student Performance

When the student is ready to perform a specific task, obtain a copy of the job sheet which may be found in either the teacher or student edition. Then observe the student performing the procedure.

Process evaluation—Place a mark in the box to the left of each designated checkpoint if the student has satisfactorily achieved the step(s) for each checkpoint area. If the student is unable to correctly complete the procedure, have the student review the materials and try again.

Product evaluation—Once the student has satisfactorily completed the procedure, rate the student product (outcome) using the criteria which have been provided as part of the job sheet. If the student's product is unacceptable, have the student review the materials and submit another product for evaluation.

Sample performance evaluation keys have been provided below. Many other keys are available. Select one rating (grading scale) which best fits your program needs.

Option A

4 - Skilled—Can perform job with no additional training.
3 - Moderately skilled—Has performed job during training program; limited additional training may be required.
2 - Limited skill—Has performed job during training program; additional training is required to develop skill.
1 - Unskilled—Is familiar with process, but is unable to perform job.

Option B

Yes—Can perform job with no additional training.

No—Is unable to perform job satisfactorily.

Servo Robot Operations
Unit 3

Answers to Assignment Sheets

Assignment Sheet 1

1. 610 mm. (24.4")
2. Vertical articulated robot, 5 axis plus servo gripper
3. Gears, timing belts, lead screw
4. Axis 1: Base rotation 310°
   Axis 2: Shoulder rotation +130° to −35°
   Axis 3: Elbow rotation +130°
   Axis 4: Wrist pitch +130°
   Axis 5: Wrist roll (unlimited)
5. DC servo gripper
6. 75mm (2.95") without rubber pads/65mm (2.56") with rubber pads
7. DC servo
8. Approx. 11kg (24 lb.)
9. Fixed reference positions on each axis by means of microswitches
10. Gripper can measure objects (by means of software). Gripper can sense gripping force
11. 600mm/sec (23.6"/sec)
12. 15 oz. in.
13. ±0.5mm (±0.02")
14. 1kg (2.2 lb.)

Assignment Sheet 2

A. Variable Definition and Manipulation Commands

a. 1
b. 5
c. 4
d. 3
e. 2
f. 6

B. Robot Control Commands

a.	1	f.	9	k.	5	p.	25	u.	20
b.	4	g.	16	l.	8	q.	3	v.	23
c.	11	h.	18	m.	12	r.	6	w.	24
d.	14	i.	22	n.	19	s.	13	x.	15
e.	7	j.	2	o.	21	t.	17	y.	10

Answers to Assignment Sheets

C. Program Control Commands

a.	1	f.	7	k.	3
b.	4	g.	12	l.	10
c.	6	h.	13	m.	8
d.	9	i.	14	n.	2
e.	11	j.	5		

D. Position Definition and Manipulation Commands

a.	1	e.	13	i.	8	m.	6
b.	4	f.	16	j.	11	n.	9
c.	7	g.	2	k.	14	o.	12
d.	10	h.	5	l.	3	p.	15

E. Program Flow Commands

a.	7	f.	6
b.	1	g.	8
c.	9	h.	2
d.	5	i.	4
e.	3	j.	10

Assignment Sheet 3

1. Disconnects physical I/O from logical I/O.
2. Connects the limit switches to the controller's input sensors. Regular input access if active.
3. Sets the state of the specified output port.
4. Disconnects the limit switches from the controller's input sensors. Regular input access is reactivated.
5. Reconnects the specified input or output to regular system control.
6. If an input is activated.
7. When in disable mode, forces the specific input or output to state 0 or 1 (off or on).
8. Displays status of all 16 inputs. If LSON is activated, will display status of all limit switches.
9. Executes a program conditional upon I/O event.
10. Displays status of all 16 outputs.
11. Displays a list of all user programs.
12. Displays current ATTACH status.
13. Displays EPROM version.
14. Displays the current configuration.
15. Displays all lines of all user programs or of a specific program.
16. Displays a list of available user memory space.
17. Displays a list of all disabled outputs and inputs.
18. Displays list of active user programs: name, priority, and status.

Answers to Assignment Sheets

19. Used in conjunction with other commands for display purposes.
20. Provides on-line help.
21. Displays string on screen, displays values of <arg).
22. Activates mode in which direct commands within running programs are not displayed.
23. Activates mode in which direct commands within running programs are displayed on screen.
24. Same as PRINT, but inserts line break before displayed text.
25. Displays on screen all characters that are transmitted to controller.
26. Displays the string and waits for value of <var> from the keyboard.
27. Waits for <var>, on keyboard characters to be pressed.
28. Activates mode in which keyboard entries are not displayed.
29. Goes to the first line of the program (when editing).
30. Precedes user comment line.
31. End of program, automatically written by the system.
32. Goes to previous line (when editing).
33. Allows the execution of a direct command from running user program.
34. Quits edit and checks program validity.
35. Displays list from line <n> to line <n>.
36. Erases the current line of program.

Assignment Sheets 4 and 5 — Evaluated according to the stated criteria.

Servo Robot Operations
Unit 3

Answers to Written Test

1. a. 4 d. 6
   b. 5 e. 3
   c. 2 f. 1

2. a. Low-technology controllers only develop sequencing of the various cams and have no memory capacity. This controller is used on a system where the job of the robot remains constant and has limited steps to perform.
   b. Medium-technology controllers have limited memory capacity and low-power microprocessors and are not easily reprogrammed.
   c. High-technology controllers have the capacity to control up to nine axes of the manipulator and provide the user with the ability to edit program information and change jobs by calling up new program numbers.

3. a. c. d. e. f

4. a. Point-to-point
   b. Continuous path

5. a. S
   b. C

6. a. O
   b. C
   c. O
   d. C
   e. O

7. a. O d. C
   b. C e. C
   c. O f. C

8. Any three of the following:

   a. Greater accuracy
   b. Decreased sensitivity
   c. Less noise
   d. Improved input and output impedance

9. a. 3 e. 6
   b. 2 f. 1
   c. 5 g. 4
   d. 7

Answers to Written Test

10. a. b. d. f

11. a. Positional data display
    b. Axis indicators
    c. Emergency stop
    d. Programming keys

12. a. 2
    b. 4
    c. 5
    d. 1
    e. 3

13. a. 3
    b. 5
    c. 1
    d. 7
    e. 6
    f. 2

14. a. c. d. e. g

15.

Applications	Closed Loop	Open Loop
Welding	X	
Coating and sealer applications	X	
Material handling	X	X
Machine tending	X	X
Arc/waterjet cutting	X	
Inspection	X	
Assembly	X	

Servo Robot Operations
Unit 3

Written Test

Name _____ Score _____

1. Match terms with their correct definitions by writing the corresponding numbers on the blanks provided.

_____a.	Control achieved by feedback	1. Pinch point
_____b.	The process for making a variable or system of variables conform to what is desired	2. Controller
_____c.	The heart of the robotic system: houses the circuitry for the robot's motor drive and control circuitry and serves as link between teach pendant and robot	3. Open-loop control
_____d.	The signal or data sent to the control system from a controlled machine or process to denote its response to the command signal	4. Closed-loop control
_____e.	Control achieved by driving control actuators with a sequence of programmed signals without measuring actual system response and closing the feedback loop	5. Control
_____f.	Any point where it is possible for a part of the body to be injured between the moving or stationary parts of a robot, associated equipment, or work material	6. Feedback
		7. Impedance

Written Test

2. Describe the three types of robotic controllers according to their technology level by writing a short description of each in the blanks provided.

   a. Low-technology _____

   _____

   _____

   _____

   b. Medium-technology _____

   _____

   _____

   _____

   c. High-technology _____

   _____

   _____

   _____

3. Select true statements concerning robotic controllers by writing an "X" on the blank before each true statement.

   _____a. The controller is the most complex of all robot components.

   _____b. The robot's arm and interfacing between other computers and devices is controlled by the manipulator's power supply.

   _____c. The computer and its memory are the heart of the controller.

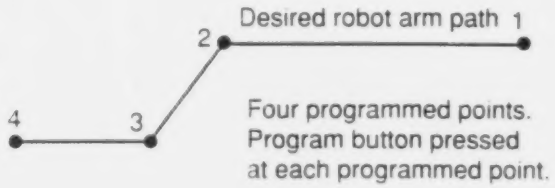
   _____d. The microprocessor(s) within the controller is responsible for the control and communication requirements of the robot and work cell.

   _____e. The input/output section must provide a communication and interface between the robot controller and the robot sensors.

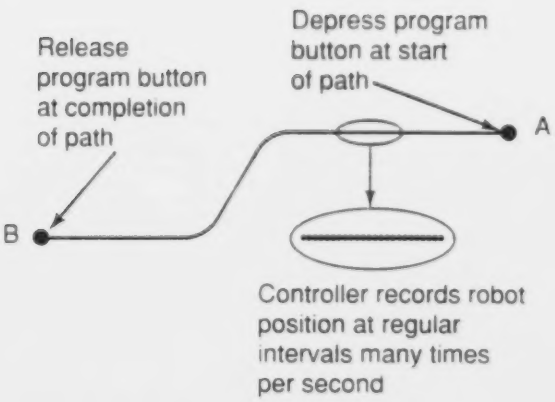
   _____f. The computer controls the motion of the robot arm by means of a drive signal that passes through the drive interface to the actuators of the arm.

Written Test

4. Identify path characteristics of robot motion control by writing the correct names in the blanks provided.



a. _____



b. _____

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5. Distinguish between the types of axis control when teaching a robot by placing an "S" for separate axis control and a "C" for coordinate axis control next to the correct descriptions.

_____a. Only one axis of the robot is operated at a time. Each movement of that axis is in separate steps, one following the other.

_____b. Several axes of the robot are operated at the same time. This allows the manipulator to rotate, move left or right, and lift or lower at the same time.

Written Test

6. Distinguish between the types of loop control by placing an "O" for open loop and a "C" for closed loop next to the correct descriptions.

   _____a. Has a reference input signal which decides the desired value of the controlled variable.

   _____b. A summing junction to subtract from the reference value to generate an error reducing the control action of the actuator as the control variable approaches.

   _____c. The output signal does not affect the input signal.

   _____d. A feedback loop measures the size and behavior of the controlled variable and then feeds a signal back to the input summing junction.

   _____e. The controlled variable is changed by a dynamic element changing it in accordance with the value of the input signal.

7. Differentiate between open loop and closed loop control systems by placing a "C" for closed loop control and an "O" for open loop control next to the correct descriptions.

   _____a. Low cost

   _____b. High-skill maintenance requirement

   _____c. Lack of speed control

   _____d. Flexible program control

   _____e. Capacity for complex manufacturing tasks

   _____f. Ease of changing programmed points

8. List three advantages of feedback on robotic operations.

   a. _____

   b. _____

   c. _____

Written Test

9. Match components of servo system control with their definitions by writing the corresponding numbers in the blanks provided.

_____a.	A tachometer generator which takes the speed of the axis and converts it to a proportional voltage level	1. Position and movement signals
_____b.	Converts the linear motion of the axis into an electrical signal	2. Positional transducer
_____c.	Produces the motor control voltage by amplifying the positional error voltage	3. Velocity transducer
_____d.	Contains circuitry which is used to directionalize the motor in a clockwise or counterclockwise direction	4. Alarm and monitoring signals
_____e.	Found in a microprocessor-based system which uses these signals from the controller to move an axis to a desired position	5. AC servo amplifier
_____f.	Programmed servo signals which are generated from the teach pendant when the operator requires movement or from the positional data stored in the controller's memory	6. Programmed servo signals
_____g.	Safety signals which indicate that the manipulator axis has moved past the programmed position or that there is high voltage to the motor, the motor is overheating, or high current to the motor	7. DC servo amplifier

10. Select true statements concerning stepper motor control by placing an "X" in the blank next to each true statement.

_____a. A stepper motor is a bidirectional, permanent magnet motor which turns through one angular increment for each pulse applied to it.

_____b. When an electronic pulse is applied to the stepper motor, it will turn and continue to turn until the applied power is removed.

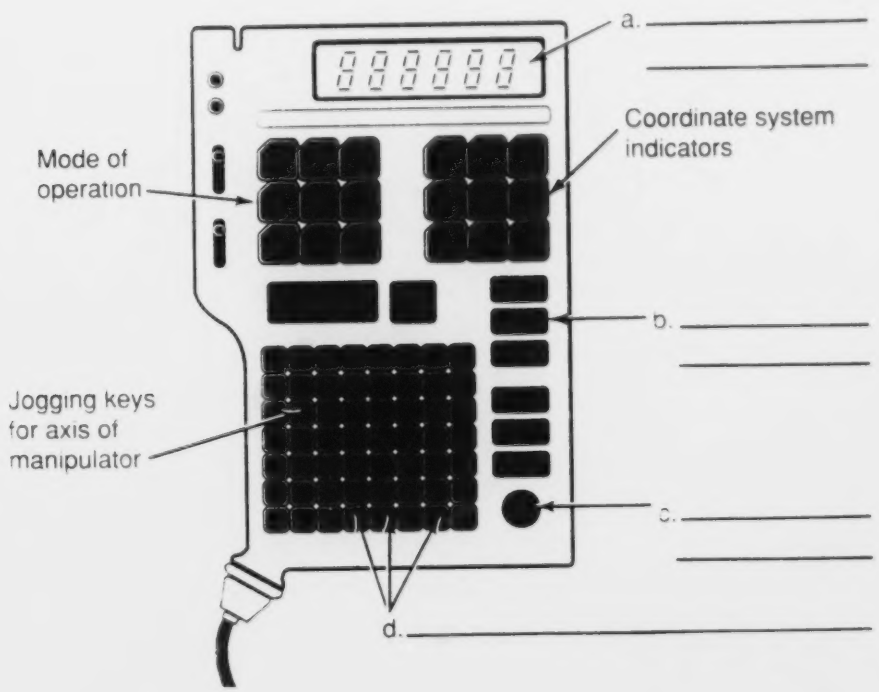
_____c. The advantage of standard motors over stepper motors is their ability to predict how far the shaft of a standard motor has rotated.

_____d. Once the computer outputs a given number of pulses, the stepper motor responds by rotating a specific number of degrees.

_____e. Stepper motors provide a large amount of torque; therefore, they are used predominately in larger robots.

_____f. Stepper motors are accurate, their positional errors are noncumulative, and they are the least expensive motor to manufacture.

11. Identify the major components of a teach pendant by writing the correct term in the blanks below.



Written Test

12. Match the components of a teach pendant with their correct functions by writing the corresponding numbers in the blanks provided.

_____a.	Indicates one of three modes (teach, test, or repeat) which the teach pendant is in	1. Programming keys
_____b.	Indicator lamps which are turned on once a system is selected to jog the robot manipulator or an axis is selected	2. Mode of operation
_____c.	Keys used for directionalizing axis motion from the minimum to the maximum of axis stroke limits	3. Emergency stop
_____d.	A set of keys used to program commands into the robot's address block or to insert, edit, or delete program information	4. Coordinate system and axis indicators
_____e.	Completely stops the robot's movement. Automatically applies the brakes to the axes causing the axes to stop and hold their position	5. Jogging keys

13. Match critical specifications of a robotic system on the right with their correct descriptions.

_____a.	Maximum weight or mass of material that can be handled satisfactorily by a machine or process in normal and continuous operation	1. Drive power
_____b.	Listing of the total number of axes of a robot and their degrees of motion	2. Memory capacity
_____c.	Source or means used to supply power to all axes of the robot	3. Payload
_____d.	Identifies the maximum variation that will occur on repeated returns to manually taught point once the program is executed	4. Weight
		5. Degrees of freedom
		6. Speed
		7. Repeatability

_____e. Measurement indicating the maximum speed that the TCP can achieve

_____f. Length of the program and/or the number of different programs that can be stored

14. Select true statements concerning servo controlled robots by placing an "X" on the blanks before each true statement.

_____a. The versatility of a servo robot is greater than that of a nonservo robot.

_____b. Servo robots cannot be programmed to stop at any position within the work envelope.

_____c. Servo robots require more complex control than nonservo robots.

_____d. Feedback is the primary difference between servo and nonservo robots.

_____e. Hydraulic and electric power sources can be used in servo controlled robots.

_____f. Electric-controlled joints or axes are moved through the use of pneumatic cylinders.

_____g. Hydraulic powered servo robots are used to carry heavy loads over 100 lbs. and even in excess of 2000 lbs.

15. Differentiate between the applications for closed loop control and open loop control by placing an "X" in the blanks under the column which applies.

Applications	Closed Loop	Open Loop
a. Welding		
b. Coating and sealer applications		
c. Material handling		
d. Machine tending		
e. Arc/waterjet cutting		
f. Inspection		
g. Assembly		

*Permission to duplicate this test is granted.

Servo Robot Operations
Unit 3

Unit Evaluation Form

Student Name _____ Unit Rating _____

Assignment Sheet 1—Determine Critical Specifications Using a Robot Manufacturer's Specification Sheet Rating _____

Comments: _____

_____

Assignment Sheet 2—Determine Meanings of Various Commands Using the *ACL Reference Guide* Rating _____

Comments: _____

_____

Assignment Sheet 3—Define Various Commands Using the *ACL Reference Guide* Rating _____

Comments: _____

_____

Assignment Sheet 4—Explain the Sequence of Operation of a Given Program Using the *ACL Reference Guide* Rating _____

Comments: _____

_____

Assignment Sheet 5—Design a Flowchart for a Robotic Application Rating _____

Comments: _____

_____

Job Sheet 1—Move and Teach a Robot Using the Teach Pendant Rating _____

Comments: _____

_____

Job Sheet 2—Develop a Flowchart and Program for a Robotic Work Cell Application Rating _____

Comments: _____

_____

Unit Evaluation Form

Written Test Scores

Pretest _____ Posttest _____ Other _____

Other _____

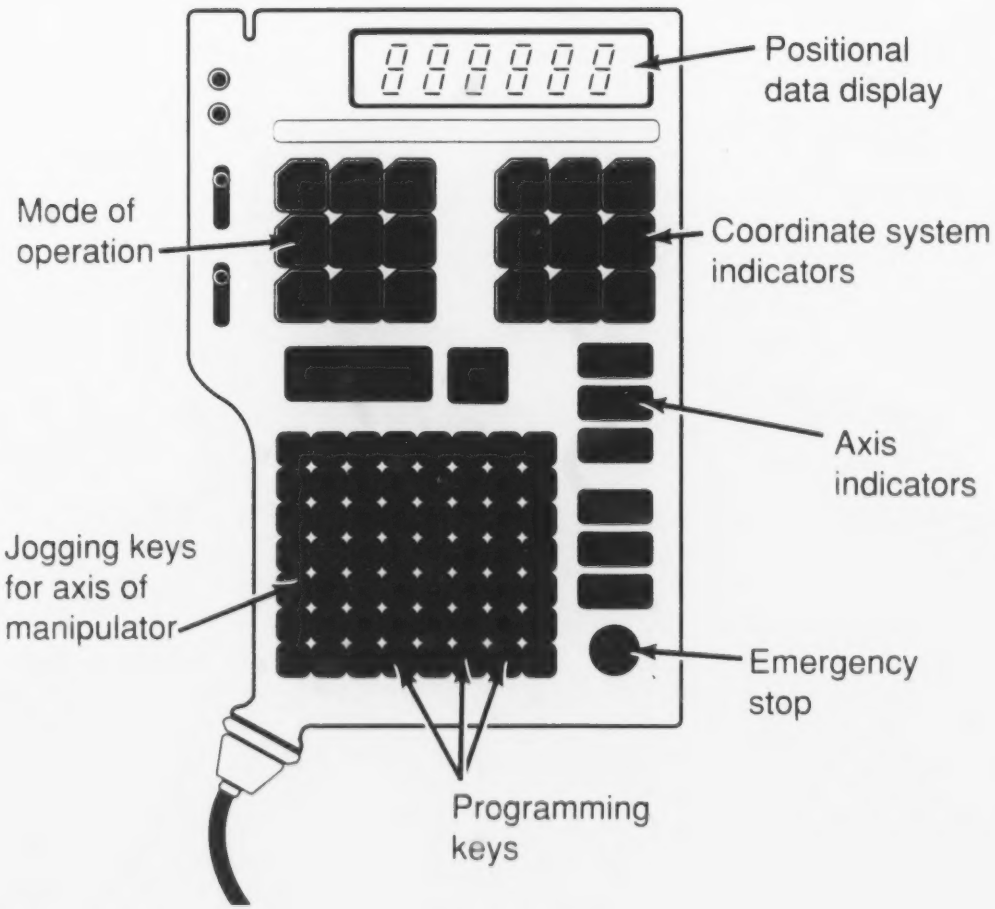
_____

Teacher Signature _____ Date _____

Student Signature _____ Date _____

*Permission to duplicate this form is granted.

Major Components of a Teach Pendant



Servo Robot Operations
Unit 3

Information Sheet

1. Terms and definitions

a. **Closed loop control** — Control achieved by feedback

Note: Closed loop control measures the degree to which actual system response conforms to desired system response and utilizes the difference to drive the system into conformance.

b. **Control** — The process for making a variable or system of variables conform to what is desired

c. **Controller** — The heart of the robotic system: houses the circuitry for the robot's motor drive and control circuitry and serves as link between teach pendant and robot

d. **Feedback** — The signal or data sent to the control system from a controlled machine or process to denote its response to the command signal

e. **Impedance** — Opposition in an electrical circuit to the flow of current

f. **Open loop control** — Control achieved by driving control actuators with a sequence of programmed signals without measuring actual system response and closing the feedback loop

g. **Pinch point** — Any point where it is possible for a part of the body to be injured between the moving or stationary parts of a robot, associated equipment, or work material

2. Types of robotic controllers according to technology level

a. Low technology controllers

(1) Only develop sequencing of the various cams and have no memory capacity

(2) Are used on systems where the job of the robot remains constant and has limited steps to perform

b. Medium technology controllers

(1) Have limited memory capacity and low-power microprocessors

(2) Are not easily reprogrammed

Information Sheet

c. High technology controllers

(1) Have the capacity to control up to nine axes of the manipulator

(2) Provide the user with the ability to edit program information and change jobs by calling up new program numbers

3. Robotic controllers

a. The controller is the most complex of all robot components.

b. The robot's arm and interfacing between other computers and devices is controlled by the controller.

c. The computer and its memory are the heart of the controller.

d. The microprocessor(s) within the controller is responsible for the control and communication requirements of the robot and work cell.

e. The input/output section must provide a communication interface between the robot controller and the following:

(1) Robot sensors

(2) Production area sensors

(3) Production area equipment

(4) Robot teaching station

(5) Permanent program storage devices

(6) Hard copy devices

(7) Other computer driven hardware

f. The computer controls the motion of the robot arm by means of a drive signal that passes through the drive interface to the actuators of the arm.

Information Sheet

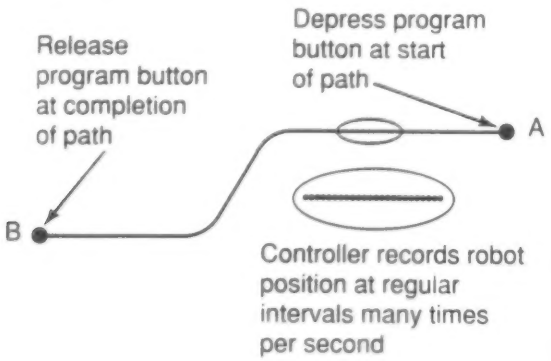
4. Path characteristics of robot motion control

a. **Continuous path**

(1) All continuous path robots are closed loop (servo controlled) systems.

(2) In programming this type of robot, the operator physically grasps the robot arm and leads the robot through the motion to be performed. The speed and moves of the robot are captured by the controller through the motion of the arm.

Figure 1—Continuous-path control


Release program button at completion of path
Depress program button at start of path
A
B
Controller records robot position at regular intervals many times per second

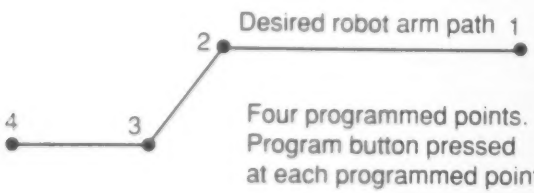
b. **Point-to-point**

(1) The operator programs each program point of the manipulator.

(2) The robot arm is then led through each point using a teach pendant.

(3) Directional buttons for each axis or a joystick is used to move the different axes.

Figure 2—Point-to-point control



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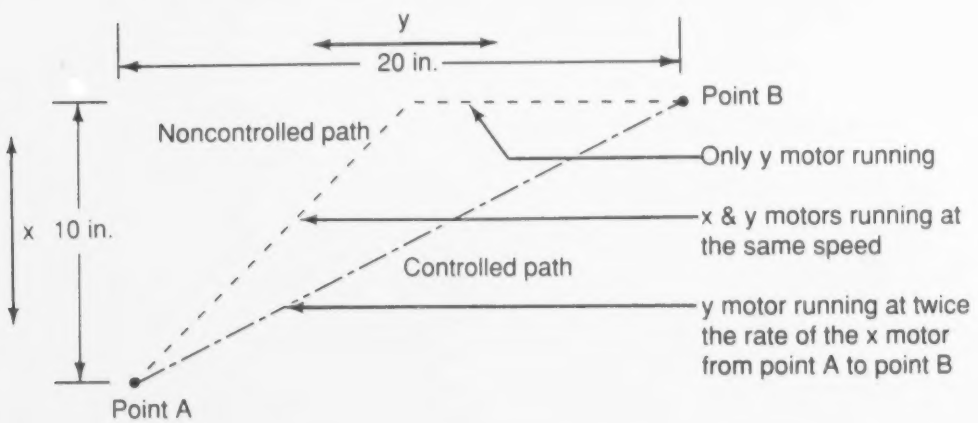
Information Sheet

c. **Noncontrolled path** — All axis drivers move at the same speed.

Note: Figure 3 shows programmed points for a two axis (x and y) robot. The points are separated by 20″ in the y direction and 10″ in the x direction. Therefore, both axis drivers are moving until the x distance is satisfied. Then only the y axis motor runs to finish the move.

Figure 3—Comparison of controlled path and noncontrolled path operation


y
20 in.
Point B
Noncontrolled path
Only y motor running
x 10 in.
x & y motors running at the same speed
Controlled path
y motor running at twice the rate of the x motor from point A to point B
Point A

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d. **Controlled path** — The axis drivers move at a speed proportional to the length of the move along the axis.

Note: In Figure 3, the driver for the y axis will move at twice the speed of the axis driver x, since y distance is twice the x distance. A straight line motion occurs. Application where straight line motion is required demands the use of controlled path robots.

Information Sheet

5. **Types of axis control when teaching a robot**

   a. **Separate axis control**

      (1) Only one axis of the robot is operated at a time.

      (2) Each movement of that axis is in separate steps, one following the other.

      Example: Once the TEACH command is pressed at the teach pendant, then the robot can be manipulated by pressing various jogging keys moving the robot's manipulator left, right, up, down, or rotating in either direction. Once all the commands are entered into the teach pendant, the robot can be placed back in the home position and the run button pressed to operate the robot. All movements of the robot will be in order as they were programmed and in separate movements.

   b. **Coordinate axis control**

      (1) Several (more than one) axes of the robot are operated at the same time.

      (2) The manipulator can rotate, move left or right, and lift or lower at the same time.

      Example: Once the TEACH command is pressed at the teach pendant, then a program number is selected and entered on the control panel. The PROGRAM button is pressed which initiates the desired robotic operating program. The next step would be to manipulate the robot by pressing various jogging keys moving the robot's manipulator. Once all the commands are entered into the teach pendant, the robot can be placed back in the home position and the run button pressed to operate the robot. All movements of the robot will occur in simultaneous movements.

6. **Types of loop control**

   a. Open loop control—Three elements distinguish the open loop control:

      (1) It has a reference input signal which decides the desired value of the controlled variable.

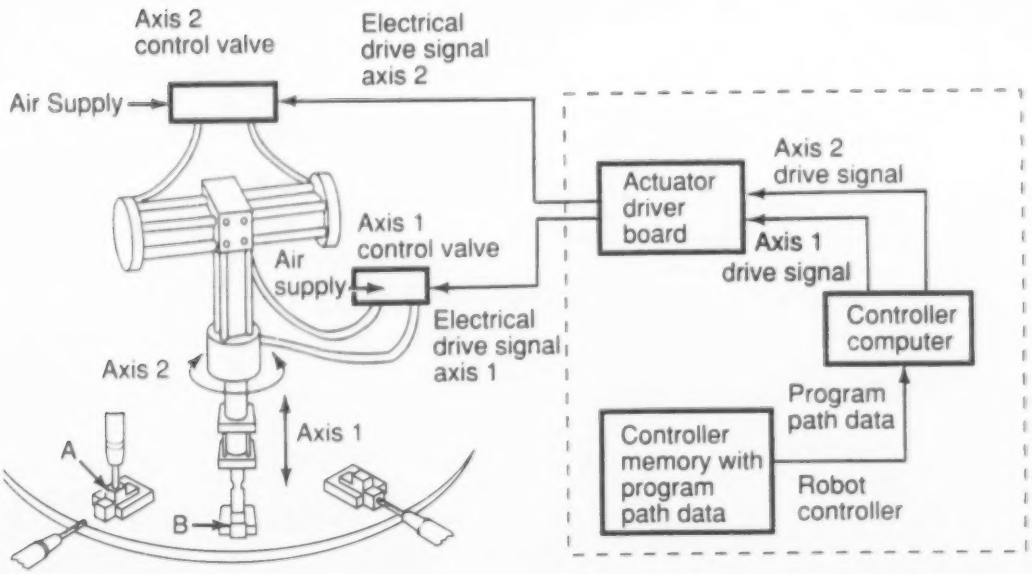
      (2) The controlled variable is changed by a dynamic element in accordance with the value of the input signal.

Information Sheet

(3) The output signal does not affect the input signal.

Example: If working with a welding application and the manipulator holding the welding rod drifted past the point it is programmed to weld, the value of the controlled variable would become incorrect and no corrective action would take place. The robot would continue to weld.

Figure 4—Open loop robot system



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Note: Figure 4 shows a two-axis robot arm and a block diagram of its controller. The robot is designed to lift a workpiece (A), rotate 180°, and replace it in its holding device (B) on an index table. This allows a third drill to produce a hole on the back side of the workpiece when the table indexes (rotates) to the next position. The robot's program sequence involves the axis 1 cylinder for lifting the workpiece and axis 2 actuator for rotating it. Axis 1 is used again for placing the workpiece back in its holder and axis 2 for rotating the arm back to its original position.

The program for this operation is stored in the controller memory. All signals flow from the controller to the robot arm actuators. There is no feedback from the robot arm to the controller to indicate the arm's positions. Therefore, it is an open loop system.

Information Sheet

b. **Closed loop control**—Two additional elements (along with the elements in open loop control) distinguish closed loop control:

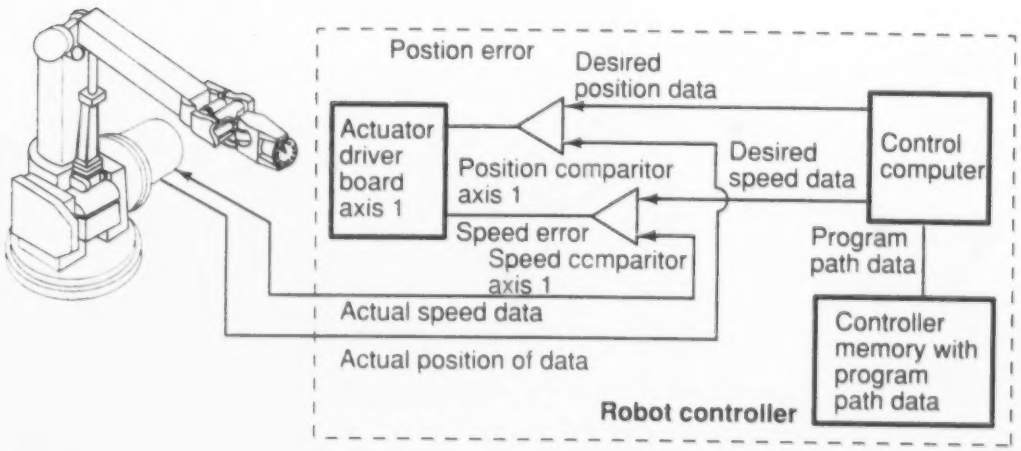
(1) A feedback loop measures the size and behavior of the controlled variable and then feeds a signal back to the input summing junction.

(2) A summing junction subtracts from the reference value to generate an error reducing the control action of the actuator as the control variable approaches.

Note: Closed loop control provides accurate positioning of the manipulator and detects the velocity and position of the axis.

Example: If working with a welding application and the manipulator holding the welding rod starts to drift past the point it is programmed to weld, the feedback loop sends a signal back to the summing junction, generating a correction to the manipulator positioning.

Figure 5—Closed loop robot system



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Note: Figure 5 is a block diagram of a closed loop robot controller for one axis of a robot arm. The primary difference between the open loop and closed loop controller is the addition of the feedback signals from the robot arm. Another addition is the ability of the controller electronics to compare actual robot axis data to the desired position and speed stored in the controller's memory.

Information Sheet

7. Advantages and disadvantages of open and closed loop control systems

Advantages	Disadvantages
a. Open Loop Control	
(1) Low cost — Because of its simplicity, the cost of this robot is at a significantly lower price.	(1) Lack of speed control — The operator has no control of the speed of the tool center point.
(2) High repeatability — Position control repeatability is commonly seen at the ±0.001 in. range.	(2) Difficulty in changing positions — Relocating a programmed position requires a mechanical change in the work cell hardware.
(3) Controller simplicity — Open loop controllers are commonly used in industry and are simple to operate.	(3) Lack of flexibility — Fixture must be placed in work cell with great precision.
b. Closed Loop Control	
(1) Flexible program control — Any point in the work envelope can be included in the program.	(1) Larger capital investment — Closed loop control robots require a larger capital investment due to their additional hardware requirements.
(2) Ease of changing programmed points — A change in the controller program is all that is necessary to change a programmed point.	(2) High skill maintenance requirement — Due to the complexity of this type of system, higher skilled maintenance people are required.
(3) Capacity for complex manufacturing tasks — Closed loop control allows for the complex manufacturing systems such as parts assembly.	
(4) Multiple program storage and execution — Several programs can be stored simultaneously. These programs can be called up by the robot's controller as necessary.	

Information Sheet

8. **Advantages of feedback on robotic operations**

   a. **Greater accuracy** — Using feedback, increased accuracy is achieved by comparing the output with the input references.

      Note: Absolute accuracy is not always achieved in some systems because of their simplicity; therefore, they will always exhibit some error.

   b. **Decreased sensitivity** — Sensitivity of a control system to unwanted disturbances and changes is reduced using feedback.

   c. **Less noise** — Feedback reduces internally generated noise.

   d. **Improved input and output impedance** — Feedback improves the impedance of the input and output by reducing or raising the input or output signals to achieve zero respectively.

9. **Components of servo system control**

   a. **Velocity transducer** — A tachometer generator which takes the speed of the axis and converts it to a proportional voltage level. This tachometer produces an AC or a DC signal at the output level.

   b. **Positional transducer** — Converts the linear motion of the axis into an electrical signal. This signal produces an AC or a DC signal, and can be either analog or digital.

   c. **AC servo amplifier** — Produces the motor control voltage by amplifying the positional error voltage.

   d. **DC servo amplifier** — Contains circuitry which is used to directionalize the motor in a clockwise or counterclockwise direction.

   e. **Programmed servo signals** — Found in a microprocessor-based system which uses these signals from the controller to move an axis to a desired position. The servo sends constant feedback to the microprocessor for updating the position of the axis.

   f. **Position and movement signals** — Programmed servo signals which are generated from the teach pendant when the operator requires movement or from the positional data stored in the controller's memory.

      Note: The microprocessor has two storage locations for positional data called registers. The command register stores the coordinates for the new axis point. The actual position register stores the actual position of the axis.

g. **Alarm and monitoring signals** — Safety signals which indicate that the manipulator axis has moved past the programmed position or that there is high voltage to the motor, high current to the motor, or an overheating motor.

Note: These signals are for the safety of the robot system and the worker. Once one of these signals occurs, the servo motor will shut down and stop the operation of the robot.

10. Stepper motor control

a. A stepper (stepping) motor is a bidirectional, permanent magnet motor which turns through one angular increment for each pulse applied to it.

b. When an electronic pulse is applied to the stepper motor, it will turn and continue to turn until the applied power is removed.

c. The advantage of stepper motors over standard motors is their ability to predict how far the shaft has rotated; it is impossible to predict the shaft rotation of a standard motor.

d. Once the computer outputs a given number of pulses, the stepper motor responds by rotating a specific number of degrees.

e. Stepper motors provide very little torque; therefore, they are not commonly used in smaller robots.

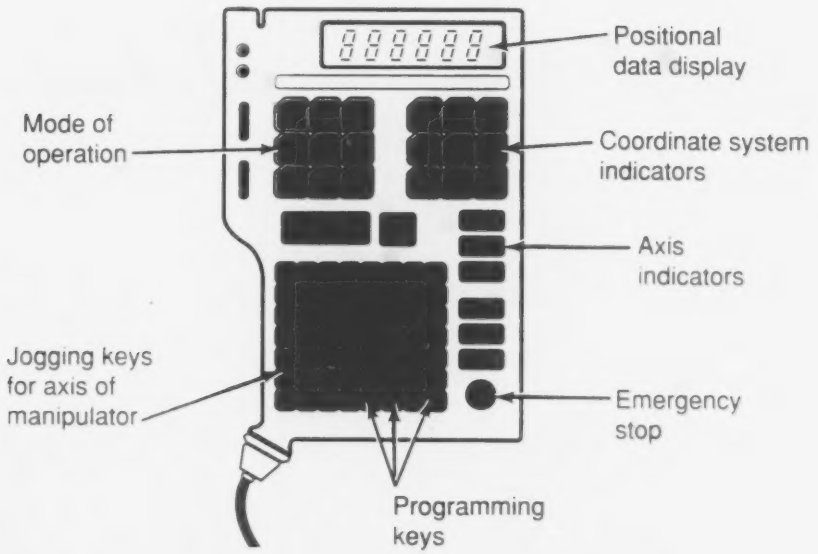
Note: Stepper motors are used in many other pieces of equipment and are often a part of the robot's work environment.

f. Stepper motors are accurate, their positional errors are noncumulative, and they are the least expensive motor to manufacture.

Information Sheet

11. Major components of a teach pendant

Figure 6



12. Teach pendant components and their functions

a. **Mode of operation** — Indicates which of three modes (teach, test, or repeat) the teach pendant is in

b. **Coordinate system and axis indicators** — Indicator lamps which are turned on once a system is selected to jog the robot manipulator or an axis is selected

c. **Jogging keys** — Keys used for directionalizing axis motion from the minimum to the maximum of axis stroke limits

d. **Programming keys** — A set of keys used to program commands into the robot's address block or to insert, edit, or delete program information

e. **Emergency stop** — Completely stops the robot's movement; automatically applies the brakes to the axes and causes the axes to stop and hold their position

Information Sheet

13. Critical specifications of a robotic system

a. **Payload** — Maximum weight or mass of material that can be handled satisfactorily by a machine or process in normal and continuous operation

b. **Degrees of freedom** — Listing of the total number of axes of a robot and their degrees of motion

c. **Drive power** — Source or means used to supply power to all axes of the robot

d. **Repeatability** — Identifies the maximum variation that will occur on repeated returns to a manually taught point once the program is executed

e. **Speed** — Measurement indicating the maximum speed that the TCP can achieve: actuator speed is given for each axis

f. **Memory capacity** — Length of the program and/or the number of different programs that can be stored

Note: For point-to-point programming, the memory capacity is the maximum number of points that can be programmed in the controller.

g. **Weight** — Identifies the weight of the robot unit

Note: Critical specifications are listed on the robot vendor's data sheet and in the operator's manual. The information provided by the vendor will vary.

Figure 7—Specifications for MAVCC prototype robot #1

Payload	23 kg (50 lb)	
Axes motion and velocity		
Axis 1 (Base)	± 150°	90 deg/sec
Axis 2 (Shoulder)	± 50°	80 deg/sec
Axis 3 (Elbow)	+ 30° to −90°	90 deg/sec
Axis 4 (Roll)	± 360°	125 deg/sec
Axis 5 (Pitch)	± 100°	150 deg/sec
Axis 6 (Roll)	± 360°	177 deg/sec
Drive power	D.C. servo motors—220 VAC, 60 Hz	
Repeatability	± 0.25 mm (±0.010 in)	
Maximum speed	500 mm/sec (20 ips)	
Memory capacity		
Number of data points	1000	
Number of program sequences	125	
Input/output contacts	8	
Weight	200 kg (440 lb)	

Information Sheet

14. Servo controlled robots

a. The versatility of a servo robot is greater than that of a nonservo robot.

b. Servo robots can be programmed to stop at any position within the work envelope.

c. Servo robots require more complex control than nonservo robots.

d. Feedback is the primary difference between servo and nonservo robots.

e. Hydraulic and electric power sources can be used in servo controlled robots.

f. Electric-controlled joints or axes are moved through the use of servo motors.

g. Hydraulic powered servo robots are used to carry heavy loads over 100 lbs. and even in excess of 2000 lbs.

Note: These robots may be used for spraying paint and in other volatile operations.

15. Applications for closed loop control and open loop control

Applications	Closed Loop	Open Loop
Welding	X	
Coating and sealer applications	X	
Material handling	X	X
Machine tending	X	X
Arc/waterjet cutting	X	
Inspection	X	
Assembly	X	

Note: Applications for open and closed loop robots are growing daily as technology is increased and hardware and control are improved.

Servo Robot Operations
Unit 3

Assignment Sheet 1—Determine Critical Specifications Using a Robot Manufacturer's Specification Sheet

Name _____ Overall Rating _____

Evaluation criteria	Rating
Determined operating parameters correctly	_____
Determined characteristics correctly	_____

Directions: Manufacturers of robotic manipulators subject their equipment to rigorous testing. The resulting data compiled from this testing will comprise the operating parameters. The characteristics of the manipulator are its limitations due to design, such as the degrees of rotation. Generally, this information is listed on a specification sheet furnished by the builder of the robot. The Scorbot®-ER V by Eshed Robotec is no exception. The *Scorbot®-ER V User's Manual* will list these items under a table named, Robot Arm Specifications. Locate this table in your *User's Manual* and complete the following:

1. What is the radius of operation of the robot?

   _____

   _____

2. What type of mechanical structure does the robot have?

   _____

   _____

3. What means are used for mechanical power transmission on the robot?

   _____

   _____

Assignment Sheet 1

4. List the operating range of each axis of the robot.

5. What type of end-of-arm tooling (EOAT) does the robot have?

6. If the EOAT is a gripper, what are the gripper opening capabilities?

7. The actuators on the manipulator are what type?

8. How much does the manipulator weigh?

9. In what way does the robot locate its hard home position?

10. Are any sensors or sensing capabilities standard on the robot?

11. The maximum path velocity of the robot is given in both inches per second and millimeters per second. What is the velocity of the robot?

Assignment Sheet 1

12. What is the peak torque in ounce-inches developed by the actuators?

_____

_____

13. The ability of a robot to return to a programmed position is known as repeatability. What is the repeatability of the robot?

_____

14. What is the maximum workload or payload of the robot?

_____

Note: It is extremely important to remember that the ability of the robot to perform to its rated repeatability is dependent upon the payload. If the robot is overloaded, it will succumb to the forces of inertia and the repeatability will suffer as well as the mechanical components.

Servo Robot Operations
Unit 3

Assignment Sheet 2—Determine Meanings of Various Commands Using the *ACL Reference Guide*

Name _____ Overall Rating _____

Evaluation criteria	Rating
Defined robot control commands correctly	_____
Defined program control commands correctly	_____
Defined definition commands correctly	_____
Defined flow commands correctly	_____

Directions: As technicians employed in the field of automated and flexible manufacturing, you will need to use the reference guides furnished with a robot. These reference guides are essential for learning a new programming language. The language used with the Scorbot®-ER V is **Advanced Control Language** or **ACL**. This language is accessible through the **Advanced Terminal Software** or **ATS**. Match the following commands used in ACL with their descriptions.

A. Variable Definition and Manipulation Commands

_____a. Creates (defines) local variables. Up to 8 variables can be defined in one command.

_____b. Creates (defines) a global variable. Up to 8 variables can be defined in one command.

_____c. Creates (defines) a local vector of *n* variables.

_____d. Creates (defines) a global vector of *n* variables.

_____e. Deletes variable from User RAM.

_____f. Mathematical and logical functions (Assigns).

1. DEFINE
2. DELVAR
3. DIMG
4. DIM
5. GLOBAL
6. SET

Assignment Sheet 2

B. Robot Control Commands

Note: Commands and descriptions for B are continued on the next page.

_____a.	Moves the robot to the specified position at the current speed. May also be programmed with time specification.	1. MOVE
_____b.	Same as the MOVE command except that program continues to the next command only when the robot has accurately reached the position.	2. OPEN
_____c.	Moves the robot from position 1 to position 3 along a circular path, through position 2.	3. HOME
_____d.	Same as MOVEC, except that the program continues to the next command only when the robot accurately reaches position.	4. MOVED
_____e.	Moves the robot along a linear path to position, at current speed. A time specification may also be added.	5. CLOSE
_____f.	Same as MOVEL, except that program continues to the next command only when the robot has accurately reached position.	6. CLR
_____g.	Moves the robot smoothly through all positions in vector, from start to end positions. No acceleration/deceleration or pausing at each position. Moves at current speed. Can be programmed with a time specification.	7. MOVEL
_____h.	Same as MOVES, except program continues to the next command only when the robot has accurately reached end position.	8. JAW
_____i.	Empties the movement buffer of all axes. It is also possible to specify groups or a specific axis.	9. MOVELD
		10. CON
		11. MOVEC
		12. SPEED
		13. COFF
		14. MOVECD
		15. SHOW SPEED
		16. MOVES
		17. TON
		18. MOVESD
		19. EXACT
		20. TOFF
		21. MPROFILE

Assignment Sheet 2

_____j. Opens the gripper to the end of motion.

_____k. Closes the gripper until the end of motion.

_____l. Puts the gripper in control loop, sets the gripper opening a variable size. Time may be specified. Must be used with caution.

_____m. Sets the current speed value for all axes. It is also possible to specify groups.

_____n. Sets movement accuracy mode.

_____o. Sets velocity profile of motion for a selected group. Used in conjunction with PRABOLOID or TRAPEZE.

_____p. Turn on integral servo control to a specified axis. Used with ON or OFF.

_____q. Drives all robot axes or a specified axis to home position.

_____r. Clears (zeros) the value of specific encoder.

_____s. Turns off servo control. May specify groups or axis.

_____t. Turns on thermic motor protection for all axes or a specific axis.

_____u. Turns off thermic motor protection for all axes or a specific axis.

_____v. Sets the DAC value for a specific axis. Used for open loop control.

_____w. Displays the DAC value for the specific axis in millivolts.

_____x. Turns servo control on for all axes or only a specified group or axis.

22. CLRBUF

23. SET ANOUT

24. SHOW DAC

25. INT

Assignment Sheet 2

C. Program Control Commands

_____a.	Runs a user program. A priority number may be added.	1. RUN
_____b.	Immediately aborts all running user programs, and stops axis movement. A single program may be specified.	2. PRIORITY
_____c.	Aborts all running programs. A single program may be specified.	3. POST
_____d.	Suspends execution of a program	4. A (ABORT)
_____e.	Resumes the running of a program previously halted by SUSPEND.	5. PEND
_____f.	Sets the value of a variable to TIME.	6. STOP
_____g.	Suspends program execution for a specified time.	7. SET TIME
_____h.	Suspends program execution until condition is satisfied (true).	8. QPOST
_____i.	Executes a program, conditional upon I/O event.	9. SUSPEND
_____j.	Suspends the execution of a program until another program posts a non-zero value to a second variable.	10. QPEND
_____k.	Attaches the value to a specified variable.	11. CONTINUE
_____l.	Same as PEND but value is taken from a queue (vector).	12. DELAY
_____m.	Same as POST but value is put into a queue (vector).	13. WAIT
_____n.	Sets run time priority of <prog> or <var>.	14. TRIGGER

Assignment Sheet 2

D. Position Definition and Manipulation Commands

_____a. Creates (defines) a position in group A or B or axis in group C.

_____b. Creates a vector of *n* positions in group A or B or axis in C.

_____c. Records in joints coordinates the location of an absolute robot position.

_____d. Sets in joints coordinates the location of a robot position relative to current robot location. Or records the position relative to another position.

_____e. Sets in cartesian coordinates the location of an absolute robot position.

_____f. Sets in cartesian coordinates the location of a position relative to current robot position.

_____g. Sets in joints coordinates one value of an axis at a previously recorded position.

_____h. Sets in cartesian coordinates one value of an axis at a previously recorded position.

_____i. Shifts location of a position by joints value.

_____j. Shifts location of a position by a cartesian coordinate value.

_____k. Copies the value of <pos1> to <pos2>.

_____l. Initialize position values. Position values are erased, but position is still defined.

_____m. Deletes positions and position vectors from User RAM.

1. DEFP
2. SETPV
3. UNDEF
4. DIMP
5. SETPVC
6. DELP
7. HERE
8. SHIFT
9. SET PVAL
10. HERER
11. SHIFTC
12. SET PVALC
13. TEACH
14. SETP
15. SET PSTATUS
16. TEACHR

Note: More descriptions on next page.

Assignment Sheet 2

_____n. Assigns the joints value of the axis at position specified to <var>.

_____o. Assigns one cartesian coordinate value of the position to <var>.

_____p. Assigns a value to <var> according to the status of the position.

E. Program Flow Commands

_____a. Logically combines a condition with other IF commands, in an *and* relationship.

_____b. Checks the conditional relation of two variables.

_____c. Logically combines a condition with other IF commands, in an *or* relationship.

_____d. Follows IF and precedes ENDIF. Begins subroutine when IF is false.

_____e. End of IF subroutine.

_____f. Loop command. Executes subroutine for all values of variable.

_____g. End of FOR loop.

_____h. Marks a program subroutine to be executed by GOTO command.

_____i. Continues program execution with command following <label>.

_____j. Transfers control to another program. Main program suspended until GOSUB completed.

1. IF
2. LABEL
3. ENDIF
4. GOTO
5. ELSE
6. FOR
7. ANDIF
8. ENDFOR
9. ORIF
10. GOSUB

Servo Robot Operations
Unit 3

Assignment Sheet 3—Define Various Commands Using the *ACL Reference Guide*

Name _____ Overall Rating _____

Evaluation criteria	Rating
Defined I/O control commands correctly	_____
Defined display and user interface commands correctly	_____

Directions: Using the *ACL Reference Guide* define the following commands.

1. DISABLE — _____

   _____

   _____

2. LSON — _____

   _____

   _____

3. SET OUT — _____

   _____

   _____

4. LSOFF — _____

   _____

   _____

5. ENABLE — _____

   _____

   _____

Assignment Sheet 3

6. IF IN — _____

_____

_____

7. FORCE — _____

_____

_____

8. SHOW DIN — _____

_____

_____

9. TRIGGER — _____

_____

_____

10. SHOW DOUT — _____

_____

_____

11. DIR — _____

_____

_____

12. ATTACH — _____

_____

_____

13. VER — _____

_____

_____

Assignment Sheet 3

14. CONFIG — _____

_____

_____

15. LIST — _____

_____

_____

16. FREE — _____

_____

_____

17. DISABLE — _____

_____

_____

18. STAT — _____

_____

_____

19. SHOW — _____

_____

_____

20. HELP — _____

_____

_____

21. PRINT — _____

_____

_____

Assignment Sheet 3

22. QUIET — _____

_____

_____

23. NOQUIET — _____

_____

_____

24. PRINTLN — _____

_____

_____

25. ECHO — _____

_____

_____

26. READ — _____

_____

_____

27. GET — _____

_____

_____

28. NOECHO — _____

_____

_____

29. S — _____

_____

_____

Assignment Sheet 3

30. * — _____

_____

_____

31. END — _____

_____

_____

32. P — _____

_____

_____

33. @ — _____

_____

34. EXIT — _____

_____

_____

35. L — _____

_____

_____

36. DEL — _____

_____

_____

Servo Robot Operations
Unit 3

Assignment Sheet 4--Explain the Sequence of Operation of a Given Program Using the *ACL Reference Guide*

Name _____ Overall Rating _____

Evaluation criteria	Rating
Explained HOME command correctly	_____
Explained WAIT command correctly	_____
Explained MOVE command correctly	_____
Explained SET command correctly	_____
Explained IF command correctly	_____
Explained FOR command correctly	_____

Directions: Look over the ACL program below and explain its operation in your own words. Use your *ACL Reference Guide* as necessary.

```
HOME
OPEN
LABEL 1
WAIT IN[1]=1
SPEED 85
MOVED 10
SPEED 8
MOVELD 11
CLOSE
MOVELD 10
SPEED 90
MOVED 12
IF IN[2]=0
GOTO 2
ELSE
GOTO 3
ENDIF
LABEL 2
MOVED 13
SPEED 5
MOVELD 14
```

Assignment Sheet 4

```
OPEN
MOVELD 13
SPEED 90
MOVE 12
SET OUT [1]=1
DELAY 50
SET OUT[1]=0
GOTO 1
LABEL 3
MOVED 15
READ "ENTER THE NUMBER OF REPETITIONS" REPS
FOR X = 1 TO REPS
SPEED 5
MOVECD 17 16
SPEED 70
MOVED 15
ENDFOR
MOVED 18
OPEN
GOTO 1
```

Explanation

Servo Robot Operations
Unit 3

Assignment Sheet 5—Design a Flowchart for a Robotic Application

Name _____ Overall Rating _____

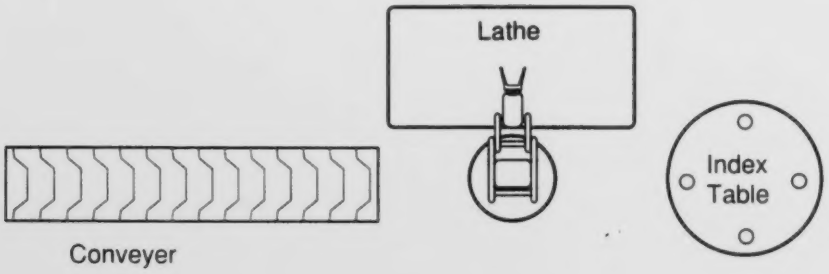
Evaluation criteria	Rating
Used proper flowchart symbology	_____
Flowchart indicates logical sequence and safe operation	_____

Directions: Using the scenario and drawing below, develop a flowchart for a robotic application.

Scenario

The Scorbot®-ER V has been chosen for a machine tending operation. The ER V will pick up 1.125 inch diameter bar stock from a transport conveyor when it receives a part present signal. It will then load the bar stock into a CNC lathe. At this time it will move to a "safe" perch position and signal the lathe to begin machining the part. When the ER V receives a signal from the lathe, it will retrieve the part and place it on an indexing table. At this time a signal will be sent to the indexing table and the machined part will be moved to the next work cell.

Figure 1



Servo Robot Operations
Unit 3

Job Sheet 1—Move and Teach a Robot Using the Teach Pendant

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Operated robot in joints coordinates	_____
Operated robot in cartesian (XYZ) coordinates	_____
Homed the robot using the teach pendant	_____
Properly ran a program using the teach pendant	_____
Properly recorded positions using the teach pendant	_____

A. Tools and materials

Scorbot®-ER V
Teach pendant and controller
Personal computer

B. Procedure

Note: Recording the positions necessary to perform the task within a work cell is one of the first steps necessary in developing a program. Follow the steps below in order to become familiar with using the teach pendant.

☐ 1. Refer to your *Scorbot®-ER V User's Manual* section on the **Teach Pendant** to become familiar with its keypad operation. Follow the steps listed in the manual. When you have completed this section, notify your instructor.

☐ 2. Refer to the subsection on **Starting the System**. Follow the steps listed in this subsection and demonstrate the operations for your instructor.

☐ 3. Refer to the subsection on **Power On and Boot the System**. Follow the steps listed in the subsection and demonstrate the operations for your instructor.

Job Sheet 1

- ☐ 4. Refer to the subsection on **Home**. Follow the steps listed. Demonstrate the homing function for your instructor.
- ☐ 5. Refer to the subsection on **Configuration**. Follow the steps listed and demonstrate them for your instructor.
- ☐ 6. Follow the steps listed under the subsections on the **Emergency Brake, Control On/Off, Test, Abort**, and **Run a Demonstration**.
- ☐ 7. Refer to the subsection on **Moving the Arm**. Follow the steps listed. Notify your instructor when you are ready to demonstrate the operations.
- ☐ 8. Refer to the subsection called **Record Position**. Follow the steps listed. Then refer to the subsection called **Move to Position**. Demonstrate the various types of movements for your instructor.
- ☐ 9. Complete the subsection on **Gripper Commands** before proceeding to the next section.
- ☐ 10. Refer to the subsection on **Writing and Running Programs**. Complete the steps as listed. Then notify your instructor.
- ☐ 11. Inputs to and Outputs from peripheral equipment are essential when programming robots. Refer to the subsection titled **Inputs/Outputs Commands**. Notify your instructor before proceeding to the next step.
- ☐ 12. Refer to the subsection on **Multi-tasking** and complete the steps. Proceed to the next step when complete.
- ☐ 13. Complete the subsection on **Moving Along a Path**.
- ☐ 14. Upon completion have your instructor check your work.
- ☐ 15. Turn off all equipment.
- ☐ 16. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

Evaluator's comments: _____

_____

_____

Servo Robot Operations
Unit 3

Job Sheet 2—Develop a Flowchart and Program for a Robotic Work Cell Application

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Developed efficient program using ACL	_____
Program execution correct	_____

A. Tools and materials

Scorbot®-ER V Robot
Robot controller with teach pendant
Personal computer

B. Procedure

- ☐ 1. Select either Scenario 1 or Scenario 2 (Part C of this job sheet).
- ☐ 2. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.
- ☐ 3. Using your flowchart, develop an ACL program to operate the Scorbot®-ER V Robot.
- ☐ 4. Teach the positions via the teach pendant.
- ☐ 5. Write the program in ACL using the personal computer.
- ☐ 6. Test your program.
- ☐ 7. Debug your program if necessary.
- ☐ 8. Upon completion, have your instructor check your work.

Job Sheet 2

☐ 9. Turn off all equipment.

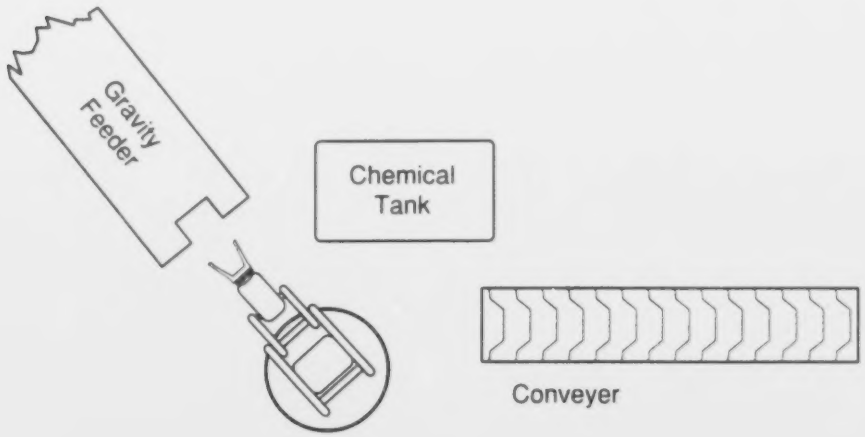
☐ 10. Check in equipment and materials and clean area.

C. Scenarios

Scenario 1: The Scorbot®-ER V servo robot has been chosen to perform the operation of submersing filter media in a tank containing a caustic chemical. The filter media is used in processing exhaust emissions. The fumes from the chemical are so toxic at this stage of the process no human workers can perform the task. The filter media is in cube form and is fed to the robot via a gravity feeder. The Scorbot®-ER V will then pick up the filter media and immerse it in the chemical tank. It is then necessary to agitate the solution. Roll the cube clockwise, then counterclockwise 5 times. At this time the cube may be removed from the chemical. It is, however, necessary to allow 30 seconds for draining while the cube is held slightly above the tank. The cube will then be placed on a conveyor to be transported to a drying area.

Complete documentation of this system is required. This will include a flowchart and a copy of the ACL code.

Figure 1



Evaluator's comments: _____

_____

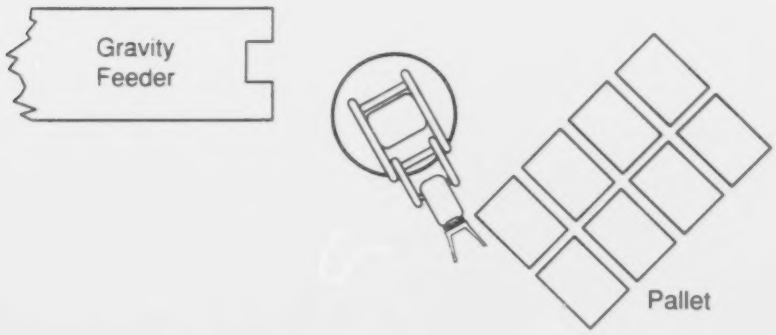
_____

Job Sheet 2

Scenario 2: As a technician for MAVCC Automated Systems, you are assigned the task of developing the program required to use the Scorbot®-ER V to palletize blocks of machinable plastic. These plastic cubes are used by the machine tool industry when manufacturing small close tolerance plastic parts. The plastic cubes are shipped in cartons of 8. As the cubes are fed to a pick up point by a gravity feeder, the robot will pick them up and place them in the carton. The carton is divided into 8 individual cubicles. When a carton is full, the system will send a signal to a conveyor controller to move the carton out and move another carton into place.

Please furnish the maintenance department with a copy of your flowchart and your program.

Figure 2



Evaluator's comments: _____

_____

_____

Sensors
Unit 4

Objective Sheet

Unit Objective

After completing this unit, the student should be able to explain the basic sensor operations of robots. The student should demonstrate these competencies by completing the assignment sheet and job sheets and by scoring a minimum of 85 percent on the written test.

Specific Objectives

After completing this unit, the student should be able to:

1. Match terms related to sensors with their correct definitions.
2. List the purposes of sensors in robot operations.
3. Describe the basic categories of sensors.
4. Complete statements concerning contact sensors.
5. Select true statements concerning noncontact sensors.
6. Select true statements concerning process control sensors.
7. Select true statements concerning sensor operations within the work cell.
8. Complete statements concerning sensor programming.
9. Choose the proper sensors for robotic applications using sensor manufacturers' catalogs. (Assignment Sheet 1)
10. Develop a flowchart and program for a robotic work cell application using a "part in place" sensor. (Job Sheet 1)
11. Develop a flowchart and program for a robotic application performing an inspection. (Job Sheet 2)
12. Develop a flowchart and program for a complete robotic work cell. (Job Sheet 3)
13. Develop a flowchart and program for a servo robotic work cell application using a "part in place" sensor. (Job Sheet 4)
14. Develop a flowchart and program for a robotic application performing a measuring/sorting operation. (Job Sheet 5)

Sensors
Unit 4

Suggested Activities

Instructional Plan

Preparation

1. Read the unit carefully and plan for instruction.
2. Review Teaching Suggestions section that follows. Plan for classroom activities.
3. Plan for students with special needs.
4. Make a transparency from the transparency master included with this unit. This appears in the teacher edition only and is designed to be used with the following objective:

   TM 1—Basic Categories of Sensors (Objective 3)

5. Obtain films, videotapes, and other resources to supplement instruction of this unit. See ordering information in the Suggested Supplemental Resources section that follows.
6. Develop teaching plan. Adjust for different learning styles.
7. Review "Instructions for Evaluating Student Performance," which follows the resources in this section of the unit. Make copies of Unit Evaluation Form, which follows the written test section.

Delivery and Application

8. Provide students with unit of instruction.
9. Discuss unit and specific objectives.
10. Discuss information sheet. Implement teaching plan to localize, supplement, and personalize the unit. Reinforce basic academic and workplace skills when applicable.
11. Discuss the assignment sheet. Review criteria for evaluation of this activity.
12. Discuss and demonstrate the job sheets. Make sure all required tools, equipment, and supplies are available. Review criteria for evaluation of these activities.

Suggested Activities

Evaluation

13. Discuss the use of the Unit Evaluation Form with students. Discuss the rating scale that will be used for student evaluation.

14. Make copies of the written test. Add or modify test items as needed.

15. Give written test.

16. Compile assignment sheet ratings, job sheet ratings, and written test scores on the Unit Evaluation Form. Include any additional assignments. Add any additional assignments or supplemental activities that should be part of the unit evaluation.

17. Reteach and retest as required.

Teaching Suggestions

Note: Skill areas appearing in boldface type in the Teaching Suggestions refer to the academic and workplace skills identified by the American Society for Training and Development (ASTD) and the U.S. Department of Labor. These have been adapted by MAVCC.

1. Introduce the unit by displaying examples of basic sensors used in the work cell. Firsthand experience with actual sensors and related equipment can increase **tactile learning**.

2. Post on a bulletin board brochures or pictures of some of the types of sensors which are not as readily available to students such as vision and tactile sensors.

3. Prior to beginning this unit, set up a demonstration using the robot within the work cell being directed by sensors. Then remove one sensor showing the students the inadequacy of the robot without sensing devices.

4. Obtain a simple contact sensor such as a limit switch and take it apart, showing the students how the switch operates.

5. After covering Objective 8, have students select an application and develop a flowchart using a sensing device. This could be a group or an individual activity. This would reinforce **creative thinking skills, problem solving skills,** and **communication skills**.

6. Additional suggestion for Assignment Sheet 1—Divide the students into groups to answer the questions orally. Have students share answers with the class.

7. Provide gridded paper and flowchart symbol templates for students to use in the job sheets requiring them to draw flowcharts.

8. The Mercury robot and the Scorbot®-ER V robot were used as the basis for the job sheets in this unit. Refer to the "Suggested Supplemental Resources" that follow for ordering information. If you plan to use other robots in your course, you will need to write substitute job sheets that cover similar tasks.

Suggested Activities

Resources Used in Developing This Unit

1. Engelberger, Joseph F. *Robotics In Practice*. Great Britain: AMACOM, 1982.

2. Hoekstra, Robert L. *Robotics and Automated Systems*. Cincinnati, OH: South-Western Publishing Company, 1986.

3. Malcolm, Douglas R., Jr. *Robotics: An Introduction*. Boston: Breton Publishers, 1985.

4. Rehg, James. *Introduction To Robotics: A Systems Approach*. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985.

5. *Robotics Institute of America Robotics Glossary*. Dearborn, MI: Robotics Institute of America, 1984.

Suggested Supplemental Resources

1. *Mercury Pneumatic Robot Laboratory Manual--B672*. Copyright 1991.

2. *Mercury Robot Control Laboratory Manual--22600*. Copyright 1991.

   The Mercury manuals are available from:

   Amatrol, Inc.
   P.O. Box 2697
   Jeffersonville, IN 47131
   Phone 812-288-8285

3. *Scorbot®-ER V User's Manual*, 2nd edition. Copyright 1991.

4. *ACL (Advanced Control Language) Reference Guide*, 3rd edition.

   The Scorbot® manual and ACL guide are available from:

   Eshed Robotec Inc.
   445 Wall Street
   Princeton, NJ 08540
   Phone 609-683-4884

Suggested Activities

Instructions For Evaluating Student Performance

When the student is ready to perform a specific task, obtain a copy of the job sheet which may be found in either the teacher or student edition. Then observe the student performing the procedure.

Process evaluation—Place a mark in the box to the left of each designated checkpoint if the student has satisfactorily achieved the step(s) for each checkpoint area. If the student is unable to correctly complete the procedure, have the student review the materials and try again.

Product evaluation—Once the student has satisfactorily completed the procedure, rate the student product (outcome) using the criteria which have been provided as part of the job sheet. If the student's product is unacceptable, have the student review the materials and submit another product for evaluation.

Sample performance evaluation keys have been provided below. Many other keys are available. Select one rating (grading scale) which best fits your program needs.

Option A

4 - Skilled—Can perform job with no additional training.
3 - Moderately skilled—Has performed job during training program; limited additional training may be required.
2 - Limited skill—Has performed job during training program; additional training is required to develop skill.
1 - Unskilled—Is familiar with process, but is unable to perform job.

Option B

Yes—Can perform job with no additional training.

No—Is unable to perform job satisfactorily.

Sensors
Unit 4

Answers to Assignment Sheet 1

1. Through scan infrared or retroreflective infrared photoelectric sensors ranging from 0-500 feet

2. Capacitive proximity sensor or through scan fiberoptic photoelectric sensors

3. Capacitive proximity, inductive proximity, or through scan fiberoptic photoelectric sensors

4. Push type limit switch

5. Capacitive or inductive proximity sensors

Sensors
Unit 4

Answers to Written Test

1.
a.	5	e.	8
b.	3	f.	7
c.	4	g.	2
d.	1	h.	6

2. Any three of the following:

   a. To protect the operator or some other human worker from harmful conditions
   b. To protect the robot or other machines from situations where they could be damaged
   c. To monitor production operations
   d. To ensure consistent product quality
   e. To detect and analyze system malfunctions
   f. To coordinate production with other systems

3. Descriptions should include:

   a. Contact sensors—Detect presence of objects when contact is made.
   b. Noncontact sensors—Detect presence of objects without making actual contact
   c. Process control sensors—Monitor variable factors in a process

4. a. Presence of an object
   b. On, off
   c. Limit switches
   d. Sensitivity
   e. Hydraulic, pneumatic
   f. Tactile sensors

5. a, c, d, e, g

6. a, b, d

7. a, b

8. a. Program control
   b. Positional offset
   c. Programmed

Sensors
Unit 4

Written Test

Name _____ Score _____

1. Match terms with their correct definitions by writing the corresponding numbers on the blanks provided.

_____a.	Switch used on robotic systems to identify when an action has occurred in the work cell	1. Actuator
_____b.	Type of interface that provides signal conditioning before analog signals can be routed to the controller	2. Analog sensors
_____c.	Sensors whose output values are in distinct digits; not continuous	3. Complex sensor interface
_____d.	Device which performs an action in response to an electrical signal	4. Digital sensors
_____e.	Changing electrical signals to a form that can be used by the controller or the actuator	5. Limit switch
_____f.	Control of a robot based on sensor readings	6. Sensor
_____g.	Sensors whose output values vary continuously and smoothly	7. Sensory control
_____h.	Type of transducer that measures some physical quantity (such as heat, light, sound, pressure, magnetism, motion, etc.) and converts it to an electrical quantity	8. Signal conditioning
		9. Simple sensor interface
		10. Transducer

Written Test

2. List three basic reasons why sensors are used in robot operations.

   a. _____

   _____

   b. _____

   _____

   c. _____

   _____

3. Describe the three basic categories of sensors.

   _____

   _____

   _____

   _____

   _____

   _____

4. Complete statements concerning contact sensors by writing the correct words in the blanks provided below.

   a. Simple contact sensors are used to detect the _____ by making contact between the object and the sensor.

   b. Simple contact sensors are either "_____" or "_____" prior to contacting the part.

   c. _____ are typical contact sensors which consist of the receptacle, body, operating head, and contacting device.

   d. Complex contact sensors provide a greater _____ level for the robot grippers in assembly applications.

   e. _____ or _____ pressure is used in robot grippers to provide pressure to hold the object selected.

   f. _____ are the primary sensors in the complex contact category.

5. Select true statements concerning noncontact sensors by placing an "X" on the blanks next to the true statements.

_____a. Photoelectric sensors detect the presence of a part in one or two ways:

(1) The part breaks a beam of light between a transmitter and a receiver, or

(2) The part reflects light from a transmitter to a receiver or target.

_____b. The through-scan photoelectric sensor uses a reflective target.

_____c. Proximity sensors detect the presence of a part when the part comes within a specified range of the sensor.

_____d. Proximity sensors may be inductive or capacitive.

_____e. Inductive types of proximity sensors detect the presence of all metal parts.

_____f. Vision sensors are simple noncontact sensors.

_____g. Vision sensors can be used for inspecting parts.

6. Select true statements concerning process control sensors by placing an "X" in the blanks next to the true statements.

_____a. Simple process control sensors are often used to monitor variable factors within a process such as temperature, pressure, level, and flow.

_____b. Process control sensors are set to trip at given values which then transmit a signal through the interface to the robot controller.

_____c. Complex process control sensors must be transmitted through the simple sensor interface.

_____d. Complex process control sensors may measure strain, pH, viscosity, color, or other variable factors.

Written Test

7. Select true statements concerning sensor operations within the work cell by writing an "X" on the blanks before the true statements.

   _____a. Various sensors are used to interface with other production systems outside the robot itself.

   _____b. Sensors provide the robot with input and output devices between the robot and the operating environment.

   _____c. Sensor inputs to the robot controller are connected through two separate interfaces--Single sensor interface and multiple sensor interface.

   _____d. Simple sensor interface operations are for all analog sensors.

   _____e. Sensors used in the complex sensor interface are digital sensors.

8. Complete statements concerning sensor programming by writing the correct words in the blanks provided.

   a. Transmitting data by the sensor and acting on that information is done through a process called _____.

   b. The program control provides two tasks:

      (1) Reading the sensor data

      (2) Developing _____ data to compensate for the sensor's data.

   c. Positional offset data tell the controller the difference between the actual position and the _____ position of the part the robot is working with.

*Permission to duplicate this test is granted.

Sensors
Unit 4

Unit Evaluation Form

Student Name _____ Unit Rating _____

Assignment Sheet 1—Choose the Proper Sensors for Robotic Applications Using Sensor Manufacturers' Catalogs Rating _____

Comments: _____

_____

Job Sheet 1—Develop a Flowchart and Program for a Robotic Work Cell Application Using a "Part in Place" Sensor Rating _____

Comments: _____

_____

Job Sheet 2—Develop a Flowchart and Program for a Robotic Work Cell Application Performing an Inspection Rating _____

Comments: _____

_____

Job Sheet 3—Develop a Flowchart and Program for a Complete Robotic Work Cell Rating _____

Comments: _____

_____

Job Sheet 4—Develop a Flowchart and Program for a Servo Robotic Work Cell Application Using a "Part in Place" Sensor Rating _____

Comments: _____

_____

Job Sheet 5—Develop a Flowchart and Program for a Robotic Work Cell Application Performing a Measuring/Sorting Operation Rating _____

Comments: _____

_____

Unit Evaluation Form

Written Test Scores

Pretest _____ Posttest _____ Other _____

Other _____

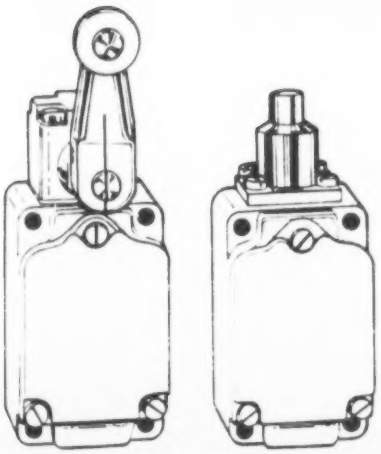
_____

Teacher Signature _____ Date _____

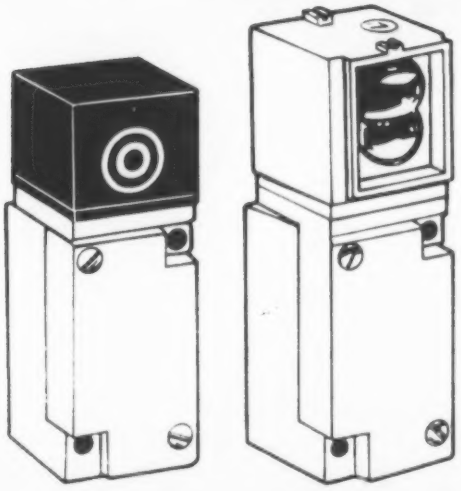
Student Signature _____ Date _____

*Permission to duplicate this form is granted.

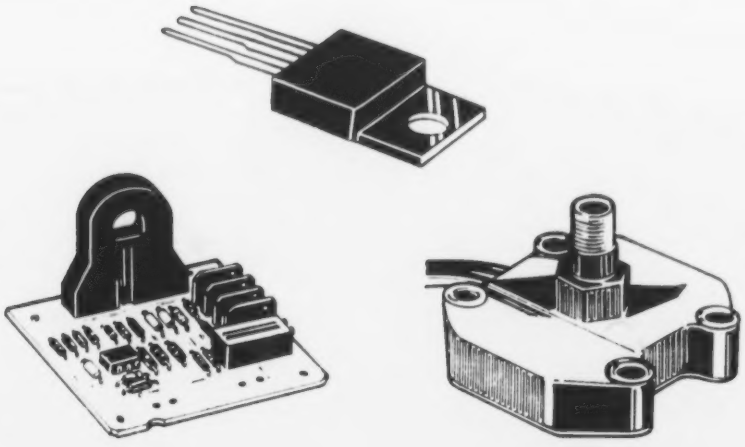
Basic Categories of Sensors



Contact Sensors



Noncontact Sensors



Process Control Sensors

Sensors
Unit 4

Information Sheet

1. Terms and definitions

a. **Actuator** — Device which performs an action in response to an electrical signal

b. **Analog sensors** — Sensors whose output values vary continuously and smoothly

c. **Complex sensor interface** — Type of interface that provides signal conditioning before analog (complex) signals can be routed to the controller

d. **Digital (discrete) sensors** — Sensors whose output values are in distinct digits: not continuous

Examples: Limit switches, proximity sensors, photoelectric sensors

Note: Digital sensors commonly send out binary signals of only two values—0 or 1, yes or no, on or off.

e. **Limit switch** — Switch used on robotic systems to identify when an action has occurred in the work cell

f. **Sensor** — Type of transducer that measures some physical quantity (such as heat, light, sound, pressure, magnetism, motion, etc.) and converts it to an electrical quantity

g. **Sensory control** — Control of a robot based on sensor readings

h. **Signal conditioning** — Changing electrical signals to a form that can be used by the controller or the actuator

Examples: Amplifying, scaling, filtering, converting from analog to digital or digital to analog

i. **Simple sensor interface** — Type of interface that handles digital (simple) signals which do not require signal conditioning

j. **Transducer** — Device actuated by power from one system and that supplies power usually in another form to a second system

Information Sheet

2. **Purposes of sensors in robot operations**

   a. To protect the operator or some other human worker from harmful conditions

   b. To protect the robot or other machines from situations where they could be damaged

   c. To monitor production operations

   d. To ensure consistent product quality

   e. To detect and analyze system malfunctions

   f. To coordinate production with other systems

   Note: Sensors provide the robot with the same data that a human would collect using the five senses. Where a human might use eyes to ensure that a part is in the proper location, the robot would rely on a sensor indicating the presence of that part (or "part in place").

3. **Basic categories of sensors**

   a. **Contact sensors** — Detect presence of objects when contact is made

   b. **Noncontact sensors** — Detect presence of objects without making actual contact

   c. **Process control sensors** — Monitor variable factors in a process

4. **Contact sensors**

   a. **Simple contact sensors**

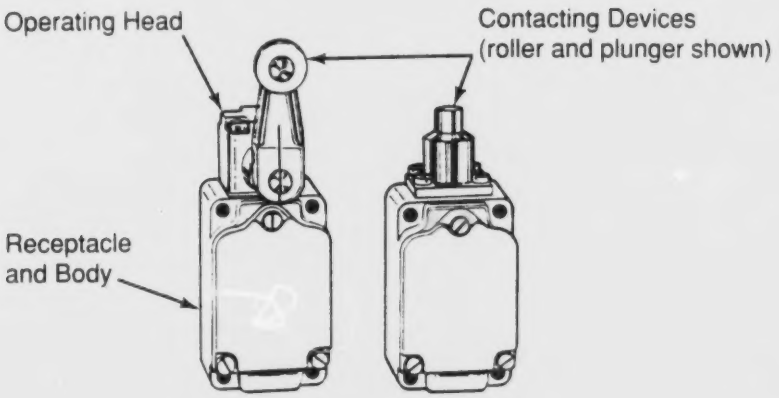
      (1) Simple contact sensors are used to detect the presence of an object by making contact between the object and the sensor.

      (2) Simple contact sensors are either "on" or "off" prior to contacting the part.

      (3) Limit switches are typical contact sensors which consist of the receptacle, body, operating head, and contacting device.

Information Sheet

Figure 1—Examples of simple contact sensors



Limit Switches

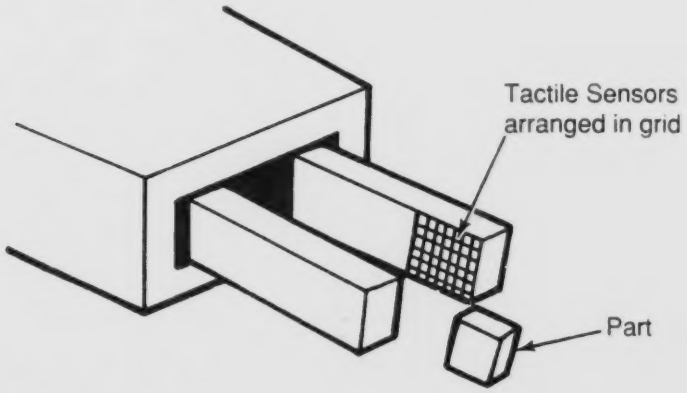
b. **Complex contact sensors**

(1) Complex contact sensors provide a greater sensitivity level for the robot grippers in assembly applications.

(2) Hydraulic or pneumatic pressure is used in robot grippers to provide pressure to hold the object selected. The pressure provided to the object is the maximum amount, thus indicating an open loop system.

(3) Tactile sensors are the primary sensors in the complex contact category.

Figure 2—Example of complex contact sensor



Information Sheet

5. Simple noncontact sensors

a. Photoelectric sensors

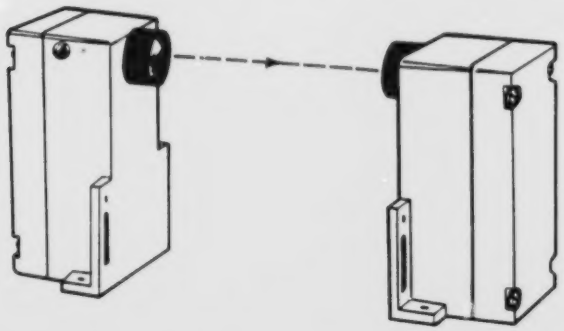
(1) Photoelectric sensors use light sources to detect the presence of a part in one of two ways:

(a) The part breaks a beam of light between a transmitter and a receiver, or
(b) The part reflects light from a transmitter to a receiver or target.

(2) There are three basic types of photoelectric sensors:

(a) Through scan—Requires two parts: light source transmitter and photoreceiver. Object to be detected passes between the two parts (through the beam).

Figure 3—Example of through scan photoelectric sensor

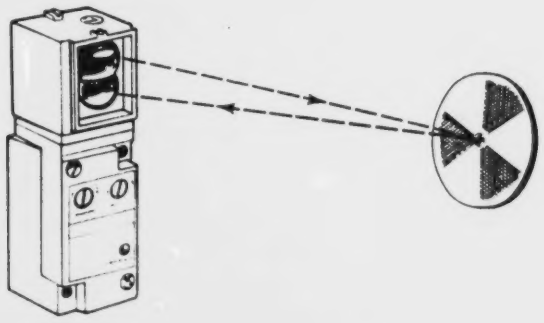


Light Source Transmitter **Photo-Receiver**

Information Sheet

(b) Retroreflective—Requires two parts: reflective target and the control unit containing both the light source transmitter and the photoreceiver. Object to be detected interrupts the beam.

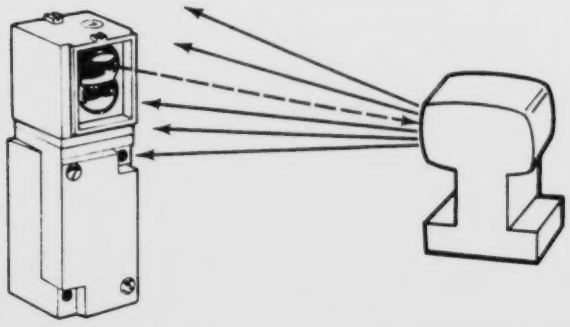
Figure 4—Example of retroreflective photoelectric sensor



Transmitter/Receiver Unit **Reflective Target**

(c) Diffuse scan—Only one part is required which consists of both the light source transmitter and the photoreceiver. Object to be detected returns the beam to the control unit.

Figure 5—Example of diffuse scan photoelectric sensor



Transmitter/Receiver Unit **Part to be Detected**

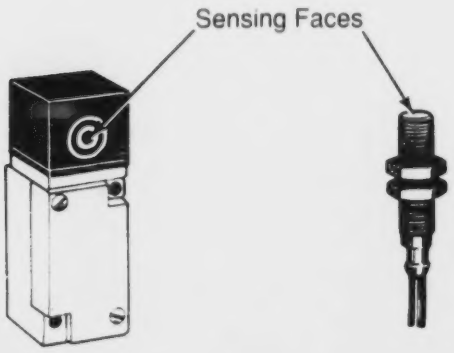
(3) Fiberoptic strands (glass or plastic) may be used to transmit the light beam.

Information Sheet

b. **Proximity sensors**

(1) Proximity sensors detect the presence of a part when the part comes within a specified range (proximity) of the sensor.

Figure 6—Examples of proximity sensors



(2) Proximity sensors may be inductive or capacitive.

(a) Inductive type sense all metals.
(b) Capacitive type sense metals and nonmetals.

(3) Proximity sensors are equipped with AC or DC output and can be interfaced directly with robot controllers, PLCs, and other hardware within the work cell.

c. **Vision sensors**

(1) Vision sensors are complex noncontact sensors.

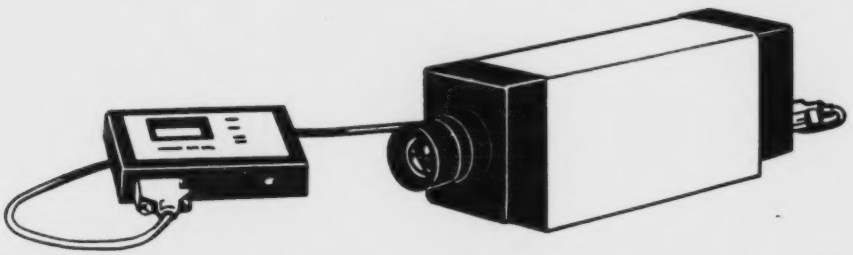
(2) Vision sensors can be used for the following tasks:

- Locating parts
- Positioning parts as required by end-of-arm tooling
- Identifying parts and rejecting parts not meeting specifications
- Inspecting parts for dimensional accuracy, surface flaws, and other quality standards

Information Sheet

(3) Vision sensors are part of a system including a camera, controller, interfacing, and image monitor.

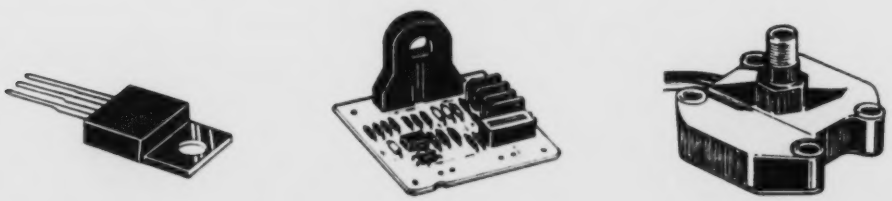
Figure 7—Example of a vision sensor system



6. Process control sensors

a. Process control sensors allow operations to be monitored and adjusted as needed throughout the production process.

Figure 8—Examples of process control sensors



Temperature **Current** **Pressure**

b. Process control sensors are set to trip at given values which then transmit signals through the interface to the robot controller.

Example: During a forging operation, a robot loads parts into an oven to heat them prior to forging. The robot then moves them to a forging press. A thermostat sensor measures the amount of heat in the oven, thus giving feedback to the robot's controller. If the oven temperature decreases below a certain point, the sensor generates a signal to the controller to halt the operation until the problem is corrected.

c. Simple process control sensors are often used to monitor temperature, pressure, level, and flow.

d. Complex process control sensors may measure strain (deformation), pH (degree of acidity or alkalinity), viscosity (resistance to flow), color, or other variable factors.

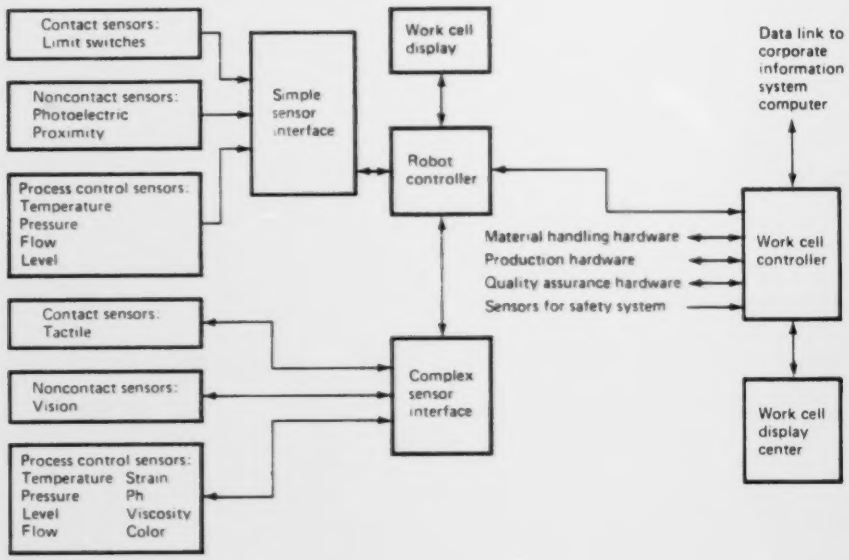
e. Complex process control sensors must be transmitted through the complex sensor interface for analog-to-digital conversion.

7. Sensor operations within the work cell

a. Various sensors are used to interface with other production systems outside the robot itself.

Example: In Figure 9 the safety sensors, which check for the presence of foreign objects in the robot work envelope, connect directly to the work cell controller. The controller has direct control of other systems in the work cell such as the material-handling hardware, production hardware, and quality-assurance equipment.

Figure 9



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Information Sheet

b. Sensors provide the robot with input and output devices between the robot and the operating environment.

c. Sensor inputs to the robot controller are connected through two separate interfaces:

(1) Simpie sensor interface

(2) Complex sensor interface

d. Simple sensor interface operations are for digital (discrete) sensors.

e. Sensors used in the complex sensor interface are either analog sensors or sensors which require additional signal conditioning before the data can be processed by the controller.

Example: A sensor providing an analog temperature output signifies an exact temperature within its measured ranges. The analog signals must be converted prior to being sent to the controller.

8. Sensor programming

a. Transmitting data by the sensor and acting on that information is done through a process called program control.

b. The program control provides two tasks:

(1) Reading the sensor data

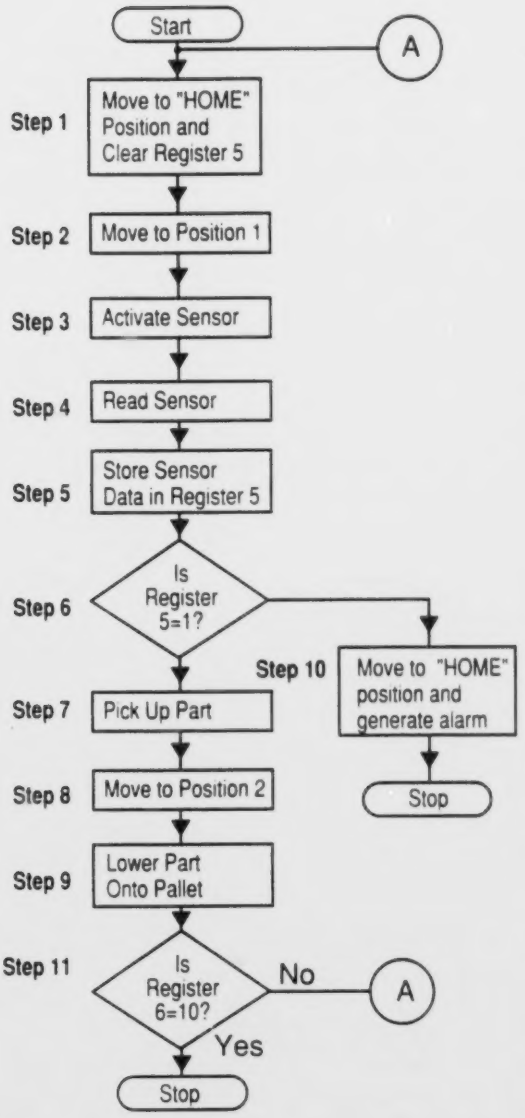
(2) Developing positional offset data to compensate for the sensor's data.

c. Positional offset data tell the controller the difference between the actual position and the programmed position of the part the robot is working with.

d. Positional offset data can be developed by a single point of data or by two or more points.

Information Sheet

Figure 10—Example of sensor programming



Step 1
The manipulator is moved to the "HOME" position. Register 5 has been selected to keep track of whether or not the part is present.

Step 2
The manipulator is moved to Position 1.

Step 3
The sensor is activated by the controller.

Step 4
The sensor data is read by the controller.

Step 5
The data in the sensor is stored in Register 5.

Step 6
The decision block determines if the part is present or not. A 1 indicates its presence, and a 0 indicates absence.

Step 7
The part is picked up by the robot's manipulator.

Step 8
The manipulator is moved to position 2.

Step 9
The part is lowered onto the pallet.

Step 10
Tells the manipulator to move to the "HOME" position if a part is not present and to stop operation upon completion of generating an alarm.

Step 11
Tells the robot to repeat the previous steps if Register 6 is less than 10. Once Register 6 equals 10, the robot operation will stop.

Sensors
Unit 4

Assignment Sheet 1—Choose the Proper Sensors for Robotic Applications Using Sensor Manufacturers' Catalogs

Name _____ Overall Rating _____

Evaluation criteria	Rating
Chose correct sensors for applications	_____
Justified choices satisfactorily	_____

Directions: Using catalogs and manufacturers' data, determine the best choice for each application.

1. A robotic work cell can be an extremely dangerous area. In many applications it is impractical to install physical barriers to keep unauthorized personnel out. In these cases it is common practice to use noncontact sensors. These sensors must be designed to sense areas of narrow widths but extreme lengths. They must serve as an "invisible fence." Choose a sensor or sensors to form this "fence." The area to be protected is a 10′ × 10′ square. Explain your choice.

_____

_____

_____

_____

_____

_____

_____

Assignment Sheet 1

2. Plastic parts are fed via a gravity feeder to a robotic work cell. Due to the size of the gripper, it is not practical to use a limit switch to determine the presence of the part. The part is flat black in color, so light reflection is minimal. Choose a sensing device that will signal the presence of the part. Explain your choice.

3. Steel parts are fed to a robotic work cell on a conveyor. When a part enters a positioning jig on the conveyor, it will shut down the conveyor and send a signal to the robot. The parts are dark in color so reflection of light is minimal. Choose a sensor for this application.

Assignment Sheet 1

4. A robot will be used to move sheets of plate glass from a storage bin. The sheets of glass are stacked on end consecutively. A sensor must be mounted on the end of the robot arm to sense the presence of a sheet of glass. The sensor signals the robot to stop forward motion. It will turn on the vacuum pump. The robot's gripper in this case is a suction cup. Choose a sensor for this application.

5. A robotic welding work cell will be used in the manufacture of component parts for jack stands. The parts will be placed on an indexing table by an operator. When the part is clamped in place, the operator will depress two mushroom head buttons simultaneously. This will rotate the part into the work envelope. Some type of sensor must be chosen to determine the position of the index table and signal the robot to begin welding. This sensor must be able to withstand repeated use. The duty cycle of the sensor is approximately two minutes. The process is designed to operate 24 hours a day. Choose a sensor or sensors to perform this job.

Sensors
Unit 4

Job Sheet 1—Develop a Flowchart and Program for a Robotic Work Cell Application Using a "Part in Place" Sensor

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Executed program correctly	_____

A. Tools and materials

Mercury Robot
Allen Bradley SLC100 PLC
Programming device
Pneumatic power supply
Work cell with part in place sensing device

B. Procedure

- ☐ 1. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.
- ☐ 2. Using your flowchart, develop a ladder logic program to operate the Mercury Robot.
- ☐ 3. Enter your program using your programming device.
- ☐ 4. Test your program.
- ☐ 5. Debug your program if necessary.
- ☐ 6. Upon completion, have your instructor check your work.
- ☐ 7. Turn off equipment.
- ☐ 8. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

Job Sheet 1

C. Scenario:

KATCO Plastics has added a Mercury Robot to its distribution line. The line is used to distribute small plastic parts throughout the plant. The parts are fed to the Mercury's location via a gravity feeder. Mounted on the end of the gravity feeder is a limit switch. This limit switch is used to detect the presence of a plastic part. If a part is in place, the Mercury will retrieve the part from the feeder and place it on a conveyor.

Note: The scenario will differ depending on the equipment available in your robotics lab. See your instructor for the specifics of the work cell.

Figure 1

Evaluator's comments: _____

_____

_____

Sensors
Unit 4

Job Sheet 2—Develop a Flowchart and Program for a Robotic Work Cell Application Performing an Inspection

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Executed program correctly	_____

A. Tools and materials

Mercury Robot
Allen Bradley SLC100 PLC
Programming device
Pneumatic power supply
Work cell with part inspection sensor

B. Procedure

- ☐ 1. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.
- ☐ 2. Using your flowchart, develop a ladder logic program to operate the Mercury Robot.
- ☐ 3. Enter your program using your programming device.
- ☐ 4. Test your program.
- ☐ 5. Debug your program if necessary.
- ☐ 6. Upon completion, have your instructor check your work.
- ☐ 7. Turn off equipment.
- ☐ 8. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

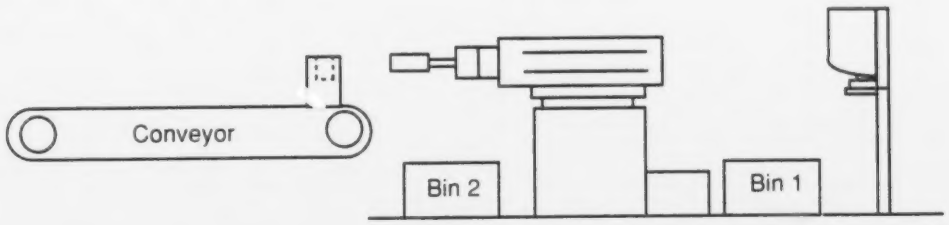
Job Sheet 2

C. Scenario:

The Mercury robot has been chosen by the engineering department to sort parts based on a simple inspection procedure. The part being inspected should have a hole drilled in one end. It will be fed to the inspection work cell via a conveyor. The robot will remove the part from the feed unit and rotate the gripper to inspect the part. If the hole is present, the limit switch will not be operated. The robot will then place the part in bin 1. If the hole is not present, the switch will signal the controller and the robot will place the part in bin 2.

Note: The scenario will differ depending on the equipment available in your robotics lab. See your instructor for the specifics of the work cell.

Figure 1



Evaluator's comments: _____

_____

_____

Sensors
Unit 4

Job Sheet 3—Develop a Flowchart and Program for a Complete Robotic Work Cell

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Executed program correctly	_____

A. Tools and materials

Mercury Robot
Allen Bradley SLC100 PLC
Programming device
Pneumatic power supply
Work cell with part in place (PIP) sensing device and inspection sensor

B. Procedure

- ☐ 1. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.
- ☐ 2. Using your flowchart, develop a ladder logic program to operate the Mercury Robot.
- ☐ 3. Enter your program using your programming device.
- ☐ 4. Test your program.
- ☐ 5. Debug your program if necessary.
- ☐ 6. Upon completion, have your instructor check your work.
- ☐ 7. Turn off equipment.
- ☐ 8. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

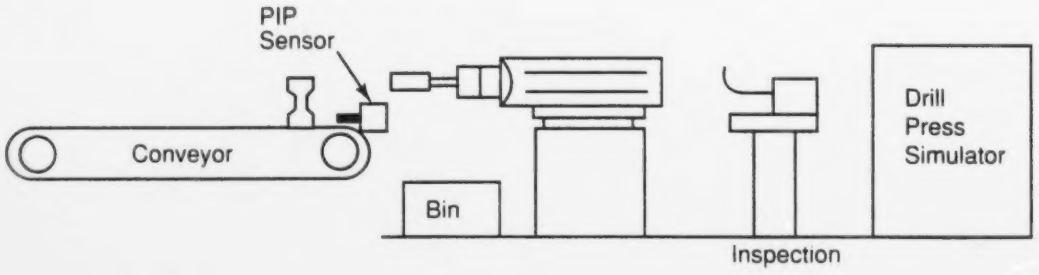
Job Sheet 3

C. Scenario:

MAVCC Automated Systems has been given the contract to completely automate the process of drilling candle holders. As an automation mechanic for MAVCC, you are assigned the task of setting up the work cell, as well as documentation and programming. The Mercury will receive a signal that a candle holder is in place in the feed unit. It will then remove the holder from the feeder and place it in the automated drill press. The controller will then signal the drill press. After the part is drilled, the drill press controller will then send a signal to the robot. The robot will remove the candle holder from the drill and rotate the part for inspection. If the hole is present, the part will be placed in a bin. If the hole is not present, a visual alarm will flash and the system will shut down.

Note: The scenario will differ depending on the equipment available in your robotics lab. See your instructor for the specifics of the work cell.

Figure 1



Evaluator's comments: _____

_____

_____

Sensors
Unit 4

Job Sheet 4—Develop a Flowchart and Program for a Servo Robotic Work Cell Application Using a "Part in Place" Sensor

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Executed program correctly	_____

A. Tools and materials

Scorbot®-ER V Robot
Robot controller with teach pendant
Personal computer

B. Procedure

- ☐ 1. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.
- ☐ 2. Using your flowchart, develop an ACL program to operate the Scorbot®-ER V Robot.
- ☐ 3. Teach the positions via the teach pendant.
- ☐ 4. Write the program in ACL using the personal computer.
- ☐ 5. Test your program.
- ☐ 6. Debug your program if necessary.
- ☐ 7. Upon completion, have your instructor check your work.
- ☐ 8. Turn off equipment.
- ☐ 9. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

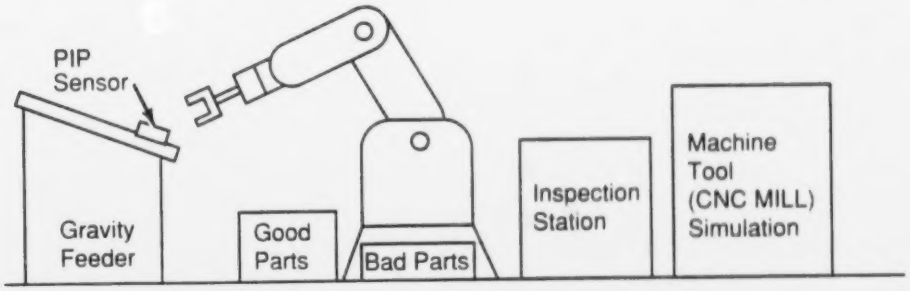
Job Sheet 4

C. Scenario:

As a technician for SARAK Manufacturing you are responsible for the programming and documentation of a servo robotic work cell. The robot will be used to load a machine tool that is performing a process on a part. A "part in place" (PIP) sensor will signal the controller that a part is in the proper location to be grasped. When the ER V grips the part, it will then place it in the machine tool's vise. A signal will then be sent to the machine tool, and the vise will clamp the part. The robot will then move to a safe "perch" position. When the machining process is complete, a signal will be sent to the controller. The part will be removed and placed in an inspection station. If all parameters are correct, two signals will be sent to the controller. In this case the part will then be moved to the "good parts" bin. If only one signal is sent to the controller, the part will be placed in the "bad parts" bin.

Note: The scenario will differ depending on the equipment available in your robotics lab. See your instructor for the specifics of the work cell.

Figure 1



Evaluator's comments: _____

_____

_____

Sensors
Unit 4

Job Sheet 5—Develop a Flowchart and Program for a Robotic Work Cell Application Performing a Measuring/Sorting Operation

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Executed program correctly	_____

A. Tools and materials

Scorbot®-ER V Robot
Robot controller with teach pendant
Personal computer
Work cell with "part in place" (PIP) sensor on the conveyor

B. Procedure

- ☐ 1. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.
- ☐ 2. Using your flowchart, develop an ACL program to operate the Scorbot®-ER V Robot.
- ☐ 3. Teach the positions via the teach pendant.
- ☐ 4. Write the program in ACL using the personal computer.
- ☐ 5. Test your program.
- ☐ 6. Debug your program if necessary.
- ☐ 7. Upon completion, have your instructor check your work.
- ☐ 8. Turn off equipment.
- ☐ 9. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

Job Sheet 5

C. Scenario:

WESTERN ROBOTICS has just secured the contract to automate the process of sorting two sizes of brass bushings based upon size. The encoder that operates the gripper sends a specific number of "counts" to the controller based on how widely it is opened or closed. This count can be seen through the SHOW ENCO command. Once this count for each size of bushing is ascertained, a program can be written to sort the bushings. Your IF THEN ELSE conditions must allow for some variance in the bushing sizes. I.e.:

```
IF SIZE > 550
MOVED 100
ELSE
IF SIZE < 200
MOVED 110
ELSE
ENDIF
ENDIF
```

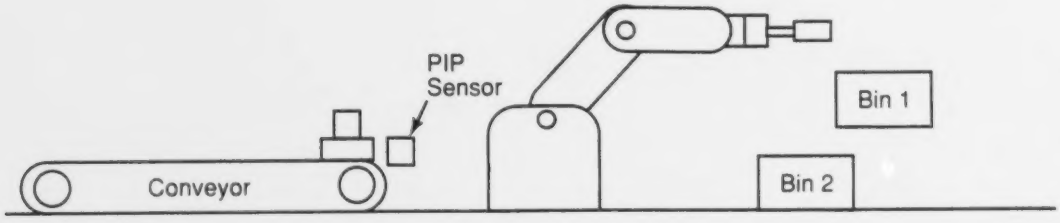
("SIZE" is a variable assigned the value of the gripper encoder.)

You must be sure to use the H HOME command on the gripper to assure that it searches for a hard stop instead of the micro switch. This will assure a count of zero on that encoder every time a part is "measured."

The bushings will be fed to the cell on a conveyor. They will be in a standing position. A limit switch will sense the presence of a part. It will then stop the conveyor and signal the robot. The robot will then place the bushing in the appropriate location, based on the encoder count.

Note: The scenario will differ depending on the equipment available in your robotics lab. See your instructor for the specifics of the work cell.

Figure 1



Job Sheet 5

Evaluator's comments: _____

_____

_____

End-of-Arm Tooling
Unit 5

Objective Sheet

Unit Objective

After completing this unit, the student should be able to explain basic end-of-arm tooling operations. The student should demonstrate these competencies by completing the assignment sheets and job sheets and by scoring a minimum of 85 percent on the written test.

Specific Objectives

After completing this unit, the student should be able to:

1. Match terms related to end-of-arm tooling with their correct definitions.
2. Describe the two basic categories of end-of-arm tooling.
3. Complete statements concerning general requirements for end-of-arm tooling.
4. List power sources used in end-of-arm tooling.
5. Select true statements concerning characteristics of grippers.
6. Complete statements describing the characteristics of vacuum devices.
7. Complete statements describing the characteristics of magnetic devices.
8. Select true statements concerning flexible pneumatic devices.
9. Differentiate between special purpose tools and special purpose devices.
10. Select true statements concerning tool center point.
11. Select true statements concerning program control for end-of-arm tooling.
12. Choose end-of-arm tooling for various robotic applications. (Assignment Sheet 1)
13. Develop a flowchart and program for a robotic work cell application using a vacuum gripper. (Job Sheet 1)
14. Develop a flowchart and program for a robotic work cell application using a sealant dispenser. (Job Sheet 2)
15. Develop a flowchart and a program for a robotic spray painting application. (Job Sheet 3)

End-of Arm Tooling
Unit 5

Suggested Activities

Instructional Plan

Preparation

1. Read the unit carefully and plan for instruction.
2. Review Teaching Suggestions section that follows. Plan for classroom activities.
3. Plan for students with special needs.
4. Obtain films, videotapes, and other resources to supplement instruction of this unit. See ordering information in the Suggested Supplemental Resources section that follows.
5. Develop teaching plan. Adjust for different learning styles.
6. Review "Instructions for Evaluating Student Performance," which follows the resources in this section of the unit. Make copies of Unit Evaluation Form, which follows the written test section.

Delivery and Application

7. Provide students with unit of instruction.
8. Discuss unit and specific objectives.
9. Discuss information sheet. Implement teaching plan to localize, supplement, and personalize the unit. Reinforce basic academic and workplace skills when applicable.
10. Discuss the assignment sheet. Review criteria for evaluation of this activity.
11. Discuss and demonstrate the job sheets. Make sure all required tools, equipment, and supplies are available. Review criteria for evaluation of these activities.

Evaluation

12. Discuss the use of the Unit Evaluation Form with students. Discuss the rating scale that will be used for student evaluation.
13. Make copies of the written test. Add or modify test items as needed.
14. Give written test.

Suggested Activities

15. Compile assignment sheet ratings, job sheet ratings, and written test scores on the Unit Evaluation Form. Include any additional assignments. Add any additional assignments or supplemental activities that should be part of the unit evaluation.

16. Reteach and retest as required.

Teaching Suggestions

Note: Skill areas appearing in boldface type in the Teaching Suggestions refer to the academic and workplace skills identified by the American Society for Training and Development (ASTD) and the U.S. Department of Labor. These have been adapted by MAVCC.

1. Introduce the unit by showing the class various examples of end-of-arm tooling. Have students guess what each device is used for (i.e., is it used for picking up an object that is smooth, round, square, etc.). This activity will help to reinforce **oral communication skills** and **problem-solving skills**.

2. Take a field trip to a local factory using an automated manufacturing process. Point out to the students the different types of end-of-arm tooling devices used in the manufacturing process.

3. To develop interest, use a bulletin board to post pictures and articles found in newspapers and magazines depicting the use of end-of-arm tooling with various robot applications.

4. Demonstrate to the students the use of the school's robot. Show how end-of-arm tooling devices are used properly, along with how the wrong device or the improper use of one can become a hinderance to the process. Stress the importance of safety.

5. In conjunction with Objective 10, give students a practical demonstration of tool center point using a selected end-of-arm tooling. Discuss the importance of tool center point when conducting precision operations. This will help to develop the students' **communication skills** and **tactile learning skills**.

6. Prior to Assignment Sheet 1, give the students a quiz on various types of end-of-arm tooling. Give the students an application and have them determine the proper device for that application.

   Note: You may wish to conduct this in small groups; however, if it is done individually, the students will be forced to use **creative thinking skills**.

Suggested Activities

Resources Used in Developing This Unit

1. Engelberger, Joseph F. *Robotics in Practice.* Great Britain: AMACOM, 1982.

2. Malcolm, Douglas R., Jr. *Robotics: An Introduction.* Boston: Breton Publishers, 1985.

3. Rehg, James. *Introduction to Robotics.* Barrington, IL: TPC Training Systems/ Technical Publishing, 1985.

4. Rehg, James. *Introduction to Robotics: A Systems Approach.* Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985.

Suggested Supplemental Resources

1. *Mercury Pneumatic Robot Laboratory Manual--B672.* Copyright 1991.

2. *Mercury Robot Control Laboratory Manual--22600.* Copyright 1991.

   The Mercury manuals are available from:

   Amatrol, Inc.
   P.O. Box 2697
   Jeffersonville, IN 47131
   Phone 812-288-8285

3. *Scorbot®-ER V User's Manual,* 2nd edition. Copyright 1991.

4. *ACL (Advanced Control Language) Reference Guide,* 3rd edition.

   The Scorbot® manual and ACL guide are available from:

   Eshed Robotec Inc.
   445 Wall Street
   Princeton, NJ 08540
   Phone 609-683-4884

Suggested Activities

Instructions For Evaluating Student Performance

When the student is ready to perform a specific task, obtain a copy of the job sheet which may be found in either the teacher or student edition. Then observe the student performing the procedure.

Process evaluation—Place a mark in the box to the left of each designated checkpoint if the student has satisfactorily achieved the step(s) for each checkpoint area. If the student is unable to correctly complete the procedure, have the student review the materials and try again.

Product evaluation—Once the student has satisfactorily completed the procedure, rate the student product (outcome) using the criteria which have been provided as part of the job sheet. If the student's product is unacceptable, have the student review the materials and submit another product for evaluation.

Sample performance evaluation keys have been provided below. Many other keys are available. Select one rating (grading scale) which best fits your program needs.

Option A

4 - Skilled—Can perform job with no additional training.
3 - Moderately skilled—Has performed job during training program: limited additional training may be required.
2 - Limited skill—Has performed job during training program: additional training is required to develop skill.
1 - Unskilled—Is familiar with process, but is unable to perform job.

Option B

Yes—Can perform job with no additional training.

No—Is unable to perform job satisfactorily.

End-of-Arm Tooling
Unit 5

Answers to Assignment Sheet 1

1. Standard two finger gripper with round stock attachment
2. Pneumatic syringe dispenser
3. Vacuum gripper with multiple cups. Cups must be spaced over the length of the surface.
4. A magnetic gripper must be used due to the holes in the stock.
5. Pneumatic spray painting system

End-of-Arm Tooling
Unit 5

Answers to Written Test

1. a. 3 d. 1
   b. 5 e. 2
   c. 6 f. 7

2. Descriptions should include:

   a. Gripping devices—Purpose is to lift and hold and/or transfer parts; may hold with standard mechanical grippers or devices using vacuums, magnets, or pneumatic pressure.
   b. Special purpose tools—Purpose is to perform various manufacturing tasks; include welding tools, drills, grinders, etc. (Examples will vary.)

3. a. Presence
   b. Light
   c. Within
   d. Simple

4. Any three of the following:

   a. Pneumatic
   b. Spring
   c. Hydraulic
   d. Electric

5. a, b, e

6. a. Lift
   b. Smooth
   c. Rubber
   d. 14.7
   e. Large
   f. Small

7. a. Ferromagnetic (or ferrous)
   b. Current
   c. Deenergized
   d. Magnetic field

8. a, c, d, e

9. a. T d. T
   b. D e. D
   c. T f. D

10. a, c

11. a, d

End-of-Arm Tooling
Unit 5

Written Test

Name _____ Score _____

1. Match terms with their correct definitions by writing the corresponding numbers on the blanks provided.

_____a.	Part of the gripper that contacts the part to be held	1. End-of-arm tooling
_____b.	Tool applied to the end of the robot's arm which allows for lifting and moving of parts	2. Ferromagnetic materials
_____c.	The amount of lifting power that a gripper has	3. Finger
_____d.	Devices or tools attached to the end of the robot's arm to accomplish given tasks	4. Flexible pneumatic devices
_____e.	Materials which contain iron and are highly attracted to a magnet	5. Gripper
_____f.	The plate on which a specified tool is attached for the robot to conduct an operation	6. Gripping force
		7. Mounting plate

2. Describe the two basic categories of end-of-arm tooling.

a. _____

_____

b. _____

_____

Written Test

3. Complete statements concerning general requirements for end-of-arm tooling by circling the correct words.

   a. The tooling must detect the (size, presence) of a part by responding to a signal.

   b. The tooling must be able to meet all the production needs and be as (light, heavy) possible.

   c. The tooling must be able to operate (outside, within) the robot's specification range.

   d. The design of the tooling should be as (simple, complex) as possible.

4. List three power sources used in end-of-arm tooling.

   a. _____

   b. _____

   c. _____

5. Select true statements concerning characteristics of grippers by placing an "X" in the blank next to each true statement.

   _____a. The two types of grippers commonly used in robotics are standard grippers and servo/nonservo grippers.

   _____b. Standard grippers use either a parallel or angular motion during operation.

   _____c. Parallel grippers have fingers that cross like scissor blades.

   _____d. Gripper fingers may be covered by metal gloves to protect delicate parts to be held.

   _____e. Tactile sensors may be used within the gripper to provide feedback controlling the degree to which the fingers open or close.

   _____f. The amount of gripping force cannot be controlled; the maximum is always used.

6. Complete statements describing the characteristics of vacuum devices by circling the correct word(s).

   a. Vacuum cups and vacuum surface plates are often used in end-of-arm tooling to (sort, lift) parts in production.

   b. The surfaces of the part to be picked up must be nearly flat, (rough, smooth) and nonporous.

   c. Vacuum cups provide "give" when they pick up a part because of their (metal, rubber) construction: therefore, they do not damage the part when making contact.

   d. The maximum lifting capacity of a single vacuum cup can be figured by taking the area of the vacuum surface and multiplying it by (10, 14.7) lbs.

   e. Several vacuum cups are often used when lifting (small, large) payloads.

   f. Vacuum surfaces plates create a vacuum on one side of a surface by using many (small, large) holes arranged in a pattern.

7. Complete statements concerning the characteristics of magnetic devices by writing the correct word(s) in the blanks provided below.

   a. Parts to be lifted by magnetic devices must be made entirely or partially of _____ material.

   b. An electromagnet is basically an iron core which is wrapped with a coil of fine wire which causes the core to become a magnet once a _____ passes through the coil.

   c. If power to the electromagnet is lost during lifting, the core becomes _____ and the part is dropped.

   d. A permanent magnet is a magnet which has a _____ present at all times.

8. Select true statements concerning flexible pneumatic devices by placing an "X" in the blank next to each true statement.

   _____a. Pneumatic fingers are used to apply pressure to an object to be gripped when the bending motion occurs.

   _____b. Mandrel lifting devices are used to lift or move parts by placing the mandrel outside the part, applying compressed air to the mandrel causing it to expand and then moving the part to the new location.

   _____c. Pin lifting devices work very similar to the mandrel devices. The gripping action of the pin lifting device occurs on the outside surface of a pin on the part to be lifted.

   _____d. One advantage in using flexible pneumatic devices is they do not damage parts during gripping due to their rubber or soft plastic construction.

   _____e. A disadvantage of using flexible pneumatic devices is they are limited in the amount in which they can lift.

9. Differentiate between special purpose tools and special purpose devices by writing "T" for special purpose tool or "D" for special purpose device in the blanks next to each example.

   _____a. Welding guns

   _____b. Circular grippers

   _____c. Spray painting guns

   _____d. Grinders

   _____e. Multiple function system

   _____f. Multiple standard grippers

10. Select true statements concerning tool center point by placing an "X" in the blank next to each true statement.

   _____a. Tool center point is the point of action for the tooling attached to the robot arm.

   _____b. Tool center point does not need to be positioned exactly in order for the tooling to perform the job successfully.

   _____c. When a tool is attached to the mounting plate, the distance from the center of the mounting plate to the position where the work is conducted is determined and must be entered into the controller through variables L, A, and B.

Written Test

11. Select true statements concerning program control for end-of-arm tooling by placing an "X" in the blank next to each true statement.

    _____a. Once tool center point is entered into the controller, the programmer controls the path of the end-of-arm tooling through the program.

    _____b. The addition of end-of-arm tooling will decrease the size of the work cell.

    _____c. Tooling is very inexpensive and most users depend on ready-made tooling.

    _____d. End-of-arm tooling is simply an extension of the robot's arm and program operation.

*Permission to duplicate this test is granted.

End-of-Arm Tooling
Unit 5

Unit Evaluation Form

Student Name _____ Unit Rating _____

Assignment Sheet 1—Choose End-of-Arm Tooling for Various Robotic Applications Rating _____

Comments: _____

_____

Job Sheet 1—Develop a Flowchart and Program for a Robotic Work Cell Application Using a Vacuum Gripper Rating _____

Comments: _____

_____

Job Sheet 2—Develop a Flowchart and Program for a Robotic Work Cell Application Using a Sealant Dispenser Rating _____

Comments: _____

_____

Job Sheet 3—Develop a Flowchart and Program for a Robotic Spray Painting Application Rating _____

Comments: _____

_____

Written Test Scores

Pretest _____ Posttest _____ Other _____

Other _____

_____

Teacher Signature _____ Date _____

Student Signature _____ Date _____

*Permission to duplicate this form is granted.

End-of-Arm Tooling
Unit 5

Information Sheet

1. **Terms and definitions**

   a. **End-of-arm tooling (EOAT)** — Devices or tools attached to the end of the robot's arm to accomplish given tasks

      Note: End-of-arm tooling may also be called end effectors.

   b. **Ferromagnetic materials** — Materials which contain iron and are highly attracted to a magnet

   c. **Finger** — Part of the gripper that contacts the part to be held

   d. **Flexible pneumatic devices** — Rubber or soft plastic items used to produce gripping capability when compressed air expands some part of their device

   e. **Gripper** — Tool applied to the end of the robot's arm which allows for lifting and moving of parts

      Note: The gripper is often referred to as the robot "hand."

   f. **Gripping force** — The amount of lifting power that a gripper has

   g. **Mounting plate** — The plate on which a specified tool is attached (mounted) for the robot to conduct an operation

2. **Basic categories of end-of-arm tooling**

   a. **Gripping devices**

      (1) Purpose is to lift and hold and/or transfer parts

      (2) May hold with standard mechanical grippers or devices using vacuums, magnets, or pneumatic pressure

   b. **Special purpose tools**

      (1) Purpose is to perform various manufacturing tasks

      (2) Include welding tools, drills, grinders, spray painting guns, glue/sealer applicators, etc.

Information Sheet

3. General requirements for end-of-arm tooling

a. The tooling must detect the presence of a part by responding to a signal.

Note: The detection signal may come from a sensor within the tooling device itself or from another area within the work cell.

b. The tooling must be able to meet all the production needs and be as light as possible.

c. The tooling must be able to operate within the robot's specification range.

Examples: Weight of tooling must not exceed payload. gripping force must be adequate for operating speed

d. The design of the tooling should be as simple as possible.

4. Power sources used in end-of-arm tooling

a. Pneumatic

b. Spring

c. Hydraulic

d. Electric

Note: Pneumatic. hydraulic. and electric power sources are also used in driving the different robot axes. Pneumatic is the primary source used in end-of-arm tooling.

5. Characteristics of grippers

a. The two types of grippers commonly used in robotics are:

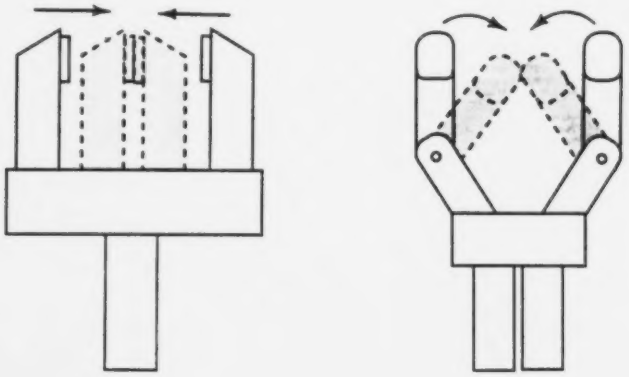
(1) Standard grippers

(2) Servo/Nonservo grippers

Information Sheet

b. Standard grippers use either a parallel or angular motion during operation.

Figure 1—Standard grippers



Parallel Angular

(1) Parallel grippers have fingers that stay parallel to each other as they open and close.

(2) Angular grippers are similar to scissors blades, opening and closing at an angle.

c. In standard grippers, the power source is used to move the gripper fingers in the direction required for gripping.

d. Servo or nonservo grippers can be used to provide open or closed loop control of the gripping operation.

e. Gripper fingers may be covered by resilent pads (rubber or plastic) to protect delicate parts to be held.

f. Gripper fingers may have self-aligning jaws to ensure good contact between the fingers and the part to be held.

g. Tactile sensors may be used within the gripper to provide feedback controlling the degree to which the fingers open or close.

h. Typically, the fingers are either open or closed and the amount of gripping force is as great as the actuator can apply.

i. The amount of gripping force can be controlled. The amount needed depends on the weight of the part, the friction between the part and the fingers, and the speed and direction of the robot.

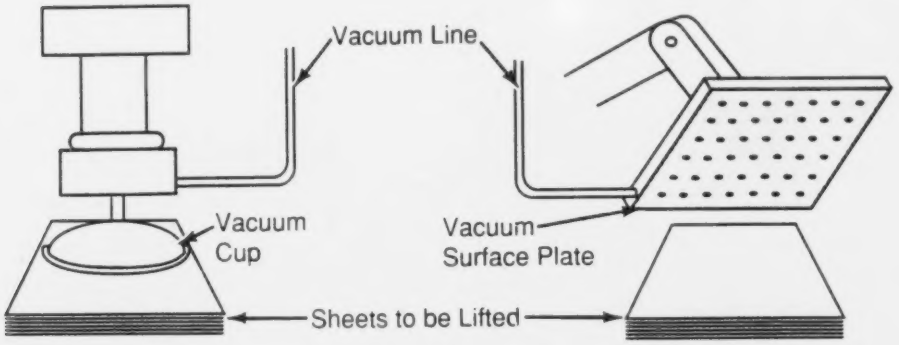
Note: Controlling gripping force is becoming a greater asset as robots become more prevalent in the workplace; however, fully open to fully closed and the maximum gripping force of the actuator are not disadvantages in most applications.

Information Sheet

6. Characteristics of vacuum devices

a. Vacuum cups and vacuum surface plates are often used in end-of-arm tooling to lift parts in production.

Figure 2—Vacuum devices



b. The surfaces of the part to be picked up must be nearly flat, smooth, and nonporous.

c. Vacuum cups provide "give" when they pick up a part because of their rubber or soft plastic construction; therefore, they do not damage the part when making contact.

d. The maximum lifting capacity of a single vacuum cup can be figured by taking the area of the vacuum surface and multiplying it by 14.7 lbs.

Example: If the vacuum cup is 15 in^2, then it should be able to lift approximately 220 pounds.

e. Several vacuum cups are often used when lifting large payloads.

Example: When lifting large sheets of cardboard, a tooling device designed with several vacuum cups is used distributing the weight of the cardboard evenly and therefore providing level lifting and moving of the cardboard.

f. Vacuum surface plates create a vacuum on one side of a surface by using many small holes arranged in a pattern. Each hole provides a small lifting force when the surface of the device comes in contact with the material or part.

Information Sheet

7. Characteristics of magnetic devices

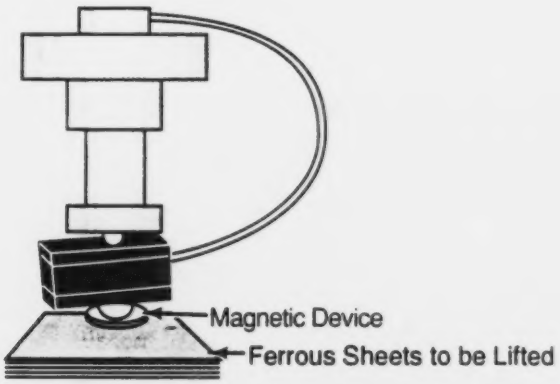
a. There are two types of magnetic devices:

(1) Electromagnets

(2) Permanent magnets

b. Parts to be lifted by magnetic devices must be made entirely or partially of ferromagnetic material.

Figure 3—Magnetic device



c. An electromagnet is basically an iron core which is wrapped with a coil of fine wire which causes the core to become a magnet once a current passes through the coil.

d. To lift heavy loads using electromagnets, the electromagnet itself must be large and heavy.

e. If power to the electromagnet is lost during lifting, the core becomes deenergized and the part is dropped.

f. A permanent magnet is a magnet which has a magnetic field present at all times. No electrical current is needed.

g. When using a permanent magnet, there is no way of releasing the part since the magnet is permanent.

h. An electromagnet can be incorporated into the permanent magnet to allow for releasing of the part. The electromagnet provides opposing field to the permanent field.

Note: When an electromagnet is added and it is desired to release the part, current is added to the electromagnet and the opposing field cancels the permanent magnet, thus releasing the part. When combining these two magnets, the size and weight of the combined magnets is doubled.

Information Sheet

8. Flexible pneumatic devices

a. The three most common flexible pneumatic devices used in automated work cells are:

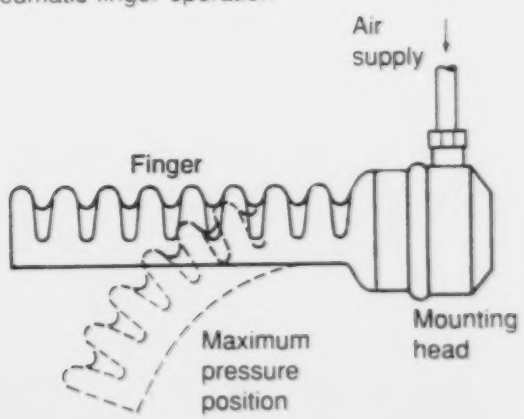
(1) Pneumatic fingers

(2) Mandrel lifting devices

(3) Pin lifting devices

b. Pneumatic fingers are used to apply pressure to an object to be gripped when the bending motion occurs.

Figure 4—Pneumatic finger operation



Note: When compressed air is not added to the finger, it remains in the straight position. As air is added to the air supply port, the finger begins to curve and applies pressure to the object to be gripped.

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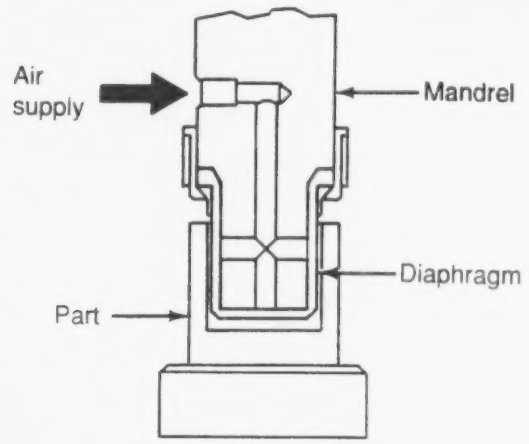
Information Sheet

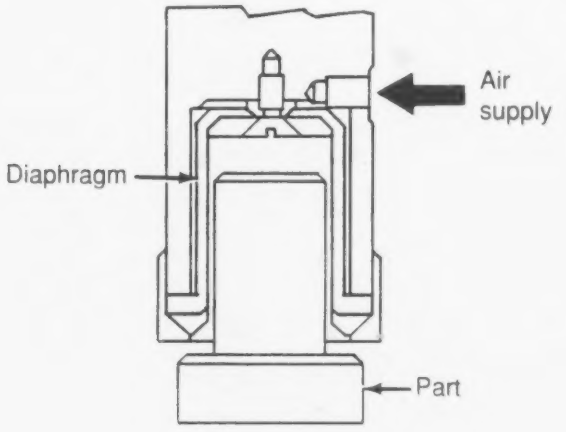
c. Mandrel lifting devices are used to lift or move parts by placing the mandrel inside a hole in the part, applying compressed air to the mandrel causing it to expand, and then moving the part to the new location.

Figure 5—Mandrel lifting device



d. Pin lifting devices work very similar to the mandrel devices. The difference is the gripping action of the pin lifting device occurs on the outside surface of a pin on the part to be lifted.

Figure 6—Pin lifting device



Illustrations reprinted with permission of TPC Training Systems — Buffalo Grove, Illinois 60089.

e. Some of the advantages in using flexible pneumatic devices are:

(1) They do not damage parts during gripping due to their rubber or soft plastic construction.

(2) Pneumatic fingers can form to irregular shapes when expanded.

(3) Their construction is simple and lightweight.

f. A disadvantage of using flexible pneumatic devices is they are limited in the amount they can lift.

9. Special purpose tools and devices

a. **Special purpose tools** — Ordinary production tools adapted for use by the robot: perform various tasks

(1) Welding guns (various types such as arc and spot)

(2) Drills

(3) Routers

(4) Grinders

(5) Sanders

(6) Spray painting guns

(7) Glue/sealer applicators

Note: Many other tools can be used. Those listed are the most common.

b. **Special purpose devices** — Unique or substantially modified end-of-arm tooling devices.

Note: These make up a large group of end-of-arm tooling and have high price tags.

(1) Special grippers such as circular grippers or multiple grippers

(2) Multiple function systems—Perform several tasks at the same time or in a certain order

(3) Custom tooling—Special tooling that must be made for a specific application or production process

Note: In most cases custom tooling is expensive and should be considered as the last resort when selecting the end-of-arm tooling needed.

Information Sheet

10. Tool center point

a. Tool center point (TCP) is the point of action for the tooling attached to the robot arm.

Figure 7—Tool Center Point

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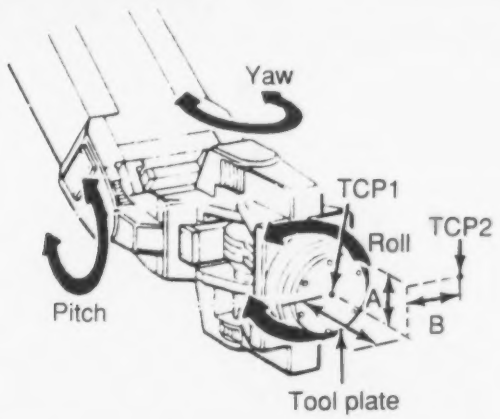
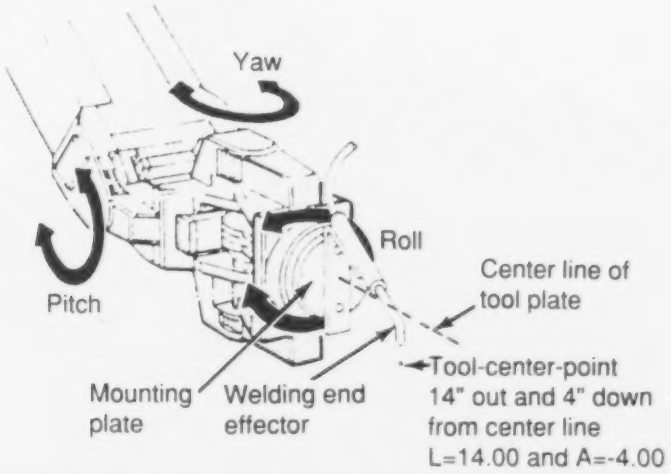


b. Tool center point must be positioned exactly in order for the tooling to perform the job successfully.

c. When a tool is attached to the mounting plate, the distance from the center of the mounting plate to the position where the work is conducted is determined and must be entered into the controller through variables L, A, and B.

Figure 8—Robot with welding tooling



Note: In the welding operation shown in Figure 4, the tool center point is the tip of the welding gun where the arc occurs.

Information Sheet

11. Program control for end-of-arm tooling

a. Once tool center point is entered into the controller, the programmer controls the path of the end-of-arm tooling through the program.

b. The program must also control the operation of the end-of-arm tooling.

Examples: Opening/closing, applying air to vacuum cups

c. The addition of end-of-arm tooling will enlarge the work cell approximately 1.5 times the original size.

Example: The standard size of an articulate robot's work envelope is approximately six feet without end-of-arm tooling. With the tooling added, the envelope would be enlarged to approximately nine feet.

d. Good tooling design can make an application successful.

e. Tooling is one of the most expensive parts within the robot operation; therefore, many users often design and build their own tooling application.

f. Accuracy and repeatability play vital roles in the tooling operations.

g. End-of-arm tooling is simply an extension of the robot's arm and program operation.

End-of-Arm Tooling
Unit 5

Assignment Sheet 1—Choose End-of-Arm Tooling for Various Robotic Applications

Name _____ Overall Rating _____

Evaluation criteria	Rating
Design will perform necessary function	_____
Sketches or drawings are clear and concise	_____
Justification is valid	_____

Direction: End-of-arm tooling (EOAT) devices are the components of robotic manipulators that actually perform the work. Generally each EOAT is designed for a specific application. Using the specifications given for each application, choose the end-of-arm tooling needed to meet the requirements. You must also justify your reasons for choosing that end-of-arm tooling.

1. The Scorbot®-ER V has been chosen to perform a machine loading operation. Four-inch lengths of 1.25 inch aluminum bar stock is fed to the robot on a gravity feeder. The part is then placed in a CNC lathe. After the part is completed, the part will be unloaded from the lathe and placed on a conveyor.

Assignment Sheet 1

2. Due to the ER V's ability to move in a circular path through its MOVEC command, it has been chosen to perform a sealant application. The sealant will be applied to flat stock that is traveling on a conveyor. A sensor will stop the conveyor and signal the robot to apply the glue in an six-inch diameter circle. After the process is complete, the robot will signal the conveyor to move.

3. The Amatrol Mercury robot has been chosen to move 18-inch long by 4.5-inch wide by .250-inch thick cardboard pieces. The cardboard will be moved from a conveyor and placed in a box that is moved into position by another conveyor. The thickness of the cardboard is such that more than one point of contact is necessary to keep the stock from buckling.

Assignment Sheet 1

4. The Mercury has also been chosen to move six- by six-inch steel plates from one conveyor to another. The steel plates will be used in a filtering process and will have .125-inch holes drilled every .5 inches.

5. A painting operation has been assigned to the ER V. The parts to be painted are six-inch by four-inch sheets of steel. They will be moved into position by an overhead conveyor. When a part is in position, a signal will be sent to the robot controller and the robot will paint the surface on one side only.

End-of-Arm Tooling
Unit 5

Job Sheet 1—Develop a Flowchart and Program for a Robotic Work Cell Using a Vacuum Gripper

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Program execution is correct	_____

A. Tools and materials

Mercury Robot
Allen Bradley SLC100 PLC
Programming device
Pneumatic power supply
Work cell with part in place sensing device
Vacuum gripper end-of-arm tooling
Vacuum pump

B. Procedure

☐ 1. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.

☐ 2. Using your flowchart, develop a ladder logic program to operate the Mercury Robot.

☐ 3. Enter your program using your programming device.

☐ 4. Test your program.

☐ 5. Debug your program if necessary.

☐ 6. Upon completion, have your instructor check your work.

Job Sheet 1

☐ 7. Turn off all equipment.

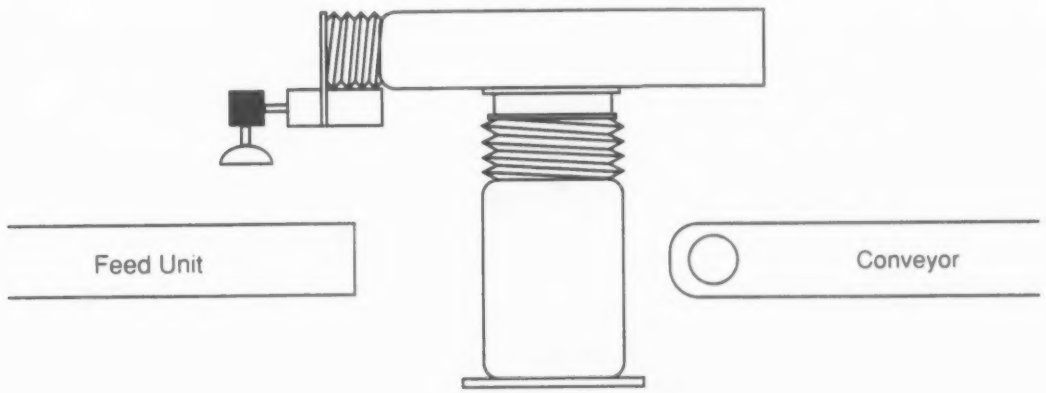
☐ 8. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

C. Scenario

The Mercury robot has been chosen for a simple pick and place operation. The parts to be moved are flat sheets of cardboard. The cardboard is delivered to the work cell on a feed unit that will allow only one piece at a time to be in position. When a sheet is in position, a signal will be sent to the robot controller. At that time the Mercury will pick up the part and rotate to a perch position. When a box moves into place on the transport conveyor, the conveyor will stop and signal the robot controller to place the flat sheet on top of the box. The robot will then move back to home position to await another sheet of cardboard.

Note: The scenario will differ depending on the equipment available in your robotics lab. See your instructor for the specifics of the work cell.

Figure 1



Evaluator's comments: _____

_____

_____

End-of-Arm Tooling
Unit 5

Job Sheet 2—Develop a Flowchart and Program for a Robotic Work Cell Application Using a Sealant Dispenser

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Developed efficient program using ACL	_____
Program execution is correct	_____

A. Tools and materials

Scorbot®-ER V Robot
Robot controller with teach pendant
Personal computer
Pneumatic syringe dispenser

B. Procedure

☐ 1. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.

☐ 2. Using your flowchart, develop an ACL program to operate the ER V Robot.

☐ 3. Teach the positions via the teach pendant.

☐ 4. Write the program in ACL using the personal computer.

☐ 5. Test your program.

☐ 6. Debug your program if necessary.

☐ 7. Upon completion, have your instructor check your work.

Job Sheet 2

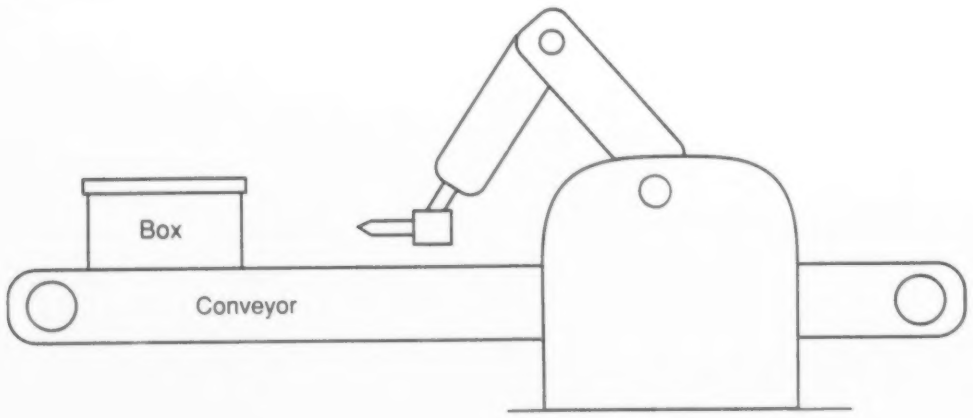
☐ 8. Turn off all equipment.

☐ 9. Check in equipment and materials and clean area, or prepare for the next job sheet as directed by your instructor.

C. Scenario

After the Scorbot®-ER V robot places the flat sheets of cardboard on top of the box, a signal is sent to move the box to the next work cell. When the box reaches this work cell, the conveyor should stop and a signal should be sent to the robot controller. The ER V will then apply a sealant or glue in a square pattern on the cardboard. After the glue has been applied, the controller will signal the conveyor to move the box to the next work cell.

Figure 1



Evaluator's comments: _____

_____

_____

End-of-Arm Tooling
Unit 5

Job Sheet 3—Develop a Flowchart and Program for a Robotic Spray Painting Application

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Identified the proper sequence of operation	_____
Developed flowchart using proper symbols	_____
Included proper information on flowchart	_____
Developed efficient program using ACL	_____
Program execution is correct	_____

A. Tools and Materials

Scorbot®-ER V Robot
Robot controller with teach pendant
Personal computer
Pneumatic spray painting system
Lead through programming software

B. Procedure

- ☐ 1. After reading the scenario and looking at the work cell, identify the proper sequence of events and draw a flowchart to reflect the proper sequence.
- ☐ 2. Using your flowchart, develop an ACL program to operate the ER V Robot.
- ☐ 3. Teach the positions via the teach pendant.
- ☐ 4. Write the program in ACL using the personal computer.
- ☐ 5. Test your program.
- ☐ 6. Debug your program if necessary.

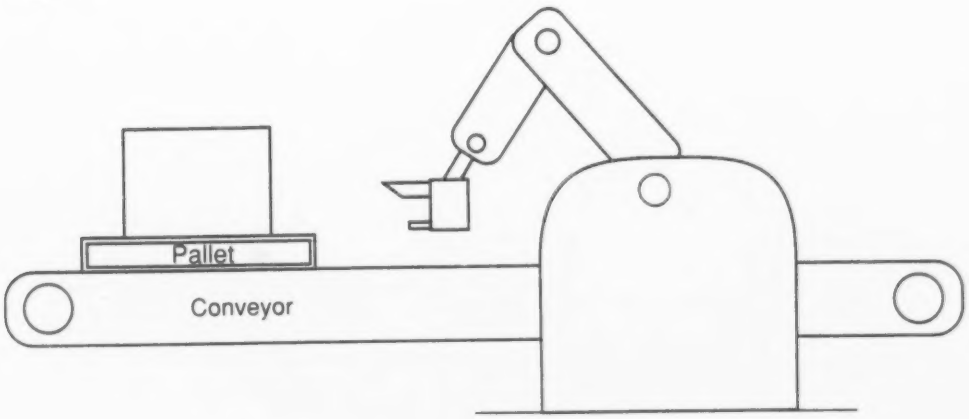
Job Sheet 3

- ☐ 7. Upon completion, have your instructor check your work.
- ☐ 8. Turn off all equipment.
- ☐ 9. Check in equipment and materials and clean area.

C. Scenario

Due to the ability of the Scorbot®-ER V to be programmed using the lead-through method, it is the perfect choice for small spray painting applications. The robot will paint sheets of flat metal that will be transported into the work cell via a conveyor. The sheets will be attached to a pallet that will allow them to be stood on end. When the controller receives a signal that a pallet is in place, it will begin the painting operation. When the stock is completely coated, the robot will return to home and the pallet will be released.

Figure 1



Evaluator's comments: _____

_____

_____

Flexible Manufacturing
Unit 6

Objective Sheet

Unit Objective

After completing this unit, the student should be able to explain basic flexible manufacturing system concepts. The students should demonstrate these competencies by completing the assignment sheet and job sheet and by scoring a minimum of 85 percent on the written test.

Specific Objectives

After completing this unit, the student should be able to:

1. Match terms related to flexible manufacturing with their correct definitions.
2. State terms for given abbreviations related to flexible manufacturing.
3. Distinguish among the three types of manufacturing.
4. Identify the basic types of manufacturing plant layouts.
5. Describe the two basic principles of flexible manufacturing.
6. Select true statements concerning the principles of computer-integrated manufacturing.
7. Complete statements concerning productivity.
8. Complete statements concerning cost of quality.
9. Complete statements concerning management by objectives.
10. Select true statements concerning just-in-time.
11. Select true statements concerning material handling.
12. Study the feasibility of creating a flexible manufacturing system to produce a product in your robotics lab. (Assignment Sheet 1)
13. Construct a flexible manufacturing system in your robotics lab. (Job Sheet 1)

Flexible Manufacturing
Unit 6

Suggested Activities

Instructional Plan

Preparation

1. Read the unit carefully and plan for instruction.
2. Review Teaching Suggestions section that follows. Plan for classroom activities.
3. Plan for students with special needs.
4. Obtain films, videotapes, and other resources to supplement instruction of this unit. See ordering information in the Suggested Supplemental Resources section that follows.
5. Develop teaching plan. Adjust for different learning styles.
6. Review "Instructions for Evaluating Student Performance," which follows the resources in this section of the unit. Make copies of Unit Evaluation Form, which follows the written test section.

Delivery and Application

7. Provide students with unit of instruction.
8. Discuss unit and specific objectives.
9. Discuss information sheet. Implement teaching plan to localize, supplement, and personalize the unit. Reinforce basic academic and workplace skills when applicable.
10. Discuss the assignment sheet. Review criteria for evaluation of these activities.
11. Discuss and demonstrate the job sheet. Make sure all required tools, equipment, and supplies are available. Review criteria for evaluation of these activities.

Evaluation

12. Discuss the use of the Unit Evaluation Form with students. Discuss the rating scale that will be used for student evaluation.
13. Make copies of the written test. Add or modify test items as needed.
14. Give written test.

Suggested Activities

15. Record assignment sheet ratings and job sheet ratings and written test scores on the Unit Evaluation Form. Add any additional assignments or supplemental activities that should be part of the unit evaluation.

16. Reteach and retest as required.

Teaching Suggestions

Note: Skill areas appearing in boldface type in the Teaching Suggestions refer to the academic and workplace skills identified by the American Society for Training and Development (ASTD) and the U.S. Department of Labor. These have been adapted by MAVCC.

1. To introduce the unit, obtain and show a film of an automated manufacturing process. Videos can help provide **motivation** and reinforce **communication skills**.

2. Discuss the term "Flexible Manufacturing System." Give students the opportunity to give their definitions of flexible manufacturing. Discussions can reinforce **creative thinking, critical thinking skills**, and **communication skills**.

3. When discussing FMS, expand on the concept of islands of automation giving examples of how they can be linked together and used to incorporate flexibility into the automated process.

4. Discuss the term "Computer-Integrated Manufacturing (CIM)." Explain the differences between CIM and FMS. Ask the students to give their input on the benefits and/or limitations of either system. Comparisons challenge **critical thinking skills**.

5. Reinforce how management by objectives (MBO) applies not only to the human worker but also to the automated machine tool and manufacturing environment. MBO philosophy states that we should try to ensure that all workers are conducting "value added" operations. This same statement applies to the tools and machinery being used.

6. While covering the Just-In-Time philosophy (Objective 10), reinforce the fact that JIT does not always mean a piece-for-piece operation. Give examples of how accumulators are used to store parts for steps in the process which are more time consuming than others.

7. Divide your class into small groups and have them design an FMS model based on given criteria from you. Use as near to real life situation based on what you have in your robotics lab. This reinforces **creative thinking** and **critical thinking skills** and can help in their **communication, interpersonal**, and **group effectiveness skills**.

Suggested Activities

Resources Used in Developing This Unit

1. Hoekstra, Robert L. *Robotics and Automated Systems.* Cincinnati, OH: Southwestern Publishing Co., 1986.

2. Malcolm, Douglas R., Jr. *Robotics: An Introduction.* Boston: Breton Publishers, 1985.

3. Rehg, James. *Introduction to Robotics.* Barrington, IL: TPC Training Systems/Technical Publishing, 1985.

4. Vail, Peter S. *Computer Integrated Manufacturing.* PWS-KENT Publishing Co., 1988.

Suggested Supplemental Resources

1. *Factory of the Future*—A series of four videotapes including:

   a. *FMS/CIM Explained*

   b. *Factory Control Systems*

   c. *A Prototypes Factory*

   d. *Building a Classroom Factory*

   These videotapes are available from:

   Bergwall Productions, Inc.
   P.O. Box 238
   Garden City, NY 11530-0238
   Phone 800-645-3565

2. Robotics tutorial software by *SHOPWARE Educational Systems*, copyright 1989. Each unit includes lessons and quizzes on copyable disks, written handout quizzes, teacher helps, and vinyl binder.

   a. *Elements of Computer Integrated Manufacturing*

   b. *Computer Aided Manufacturing*

   These software lessons are available in the following formats: Apple II, 128K 5¼"; Apple II, 128K 3½"; IBM, 128K 5¼"; IBM 128K 3½" (IBM PC needs to be CGA graphics compatible); or Macintosh. They are available from:

   Teaching Aids Inc.
   P.O. Box 1798
   Costa Mesa, CA 92628
   Phone 714-548-9321

Suggested Activities

Instructions For Evaluating Student Performance

When the student is ready to perform a specific task, obtain a copy of the job sheet which may be found in either the teacher or student edition. Then observe the student performing the procedure.

Process evaluation—Place a mark in the box to the left of each designated checkpoint if the student has satisfactorily achieved the step(s) for each checkpoint area. If the student is unable to correctly complete the procedure, have the student review the materials and try again.

Product evaluation—Once the student has satisfactorily completed the procedure, rate the student product (outcome) using the criteria which have been provided as part of the job sheet. If the student's product is unacceptable, have the student review the materials and submit another product for evaluation.

Sample performance evaluation keys have been provided below. Many other keys are available. Select one rating (grading scale) which best fits your program needs.

Option A

4 - Skilled—Can perform job with no additional training.
3 - Moderately skilled—Has performed job during training program; limited additional training may be required.
2 - Limited skill—Has performed job during training program; additional training is required to develop skill.
1 - Unskilled—Is familiar with process, but is unable to perform job.

Option B

Yes—Can perform job with no additional training.

No—Is unable to perform job satisfactorily.

Flexible Manufacturing
Unit 6

Answers to Written Test

1. a. 5
   b. 4
   c. 7
   d. 6
   e. 3
   f. 10
   g. 1

2. a. Work in process
   b. Quality control
   c. Flexible manufacturing system
   d. Computer-integrated manufacturing
   e. Just in time
   f. Computer numerical control
   g. Just in case

3. a. CO
   b. CU
   c. B

4. a. Process
   b. Product

5. Descriptions should include: (Answers will vary)

   a. Flexibility

      (1) A flexible manufacturing system (FMS) allows for a variety of products to be produced instead of just one or two.
      (2) Computer numerical controlled machines and robots are commonly used because they are flexible and can be reprogrammed quickly.

   b. Productivity

      (1) Automated and computerized machines and robots are used to increase productivity. However, they can be very expensive and must pay for themselves through increased productivity.
      (2) All areas of planning and production are analyzed to increase productivity. This includes making both machines and people work smarter and more productively.

6. a, c, d, f

Answers to Written Test

7. a. Labor
   b. Worth
   c. Machinery
   d. Base period

8. a. Customers
   b. Actual cost
   c. Zero defect
   d. Training

9. a. Performance
   b. Management
   c. Worker
   d. Meaningful
   e. Designing
   f. Group or team

10. a. c. e

11. a. b. e. f

Flexible Manufacturing
Unit 6

Written Test

Name _____ Score _____

1. Match terms with their correct definitions by writing the corresponding numbers on the blanks provided.

_____a.	Production with machines capable of making a different product without retooling or any similar changeover	1. Accumulators
_____b.	The use of a dedicated mini or microcomputer to implement the numerical control function	2. Automated guided vehicle system
_____c.	The process of taking raw materials and making them into something with a greater value	3. Automation
_____d.	A power-driven device that is not hand-held and that is used to cut, form, or shape manufacturing material	4. Computer numerical control
_____e.	The operation of machines and processing equipment without an operator controlling them; usually control is by a computer	5. Flexible manufacturing
_____f.	A system which inspects parts during the production process continually ensuring that the part meets the customers' quality requirements	6. Machine tool
_____g.	Storage bins or devices used to hold designated amounts of parts during the manufacturing process	7. Manufacturing
		8. Mechanization
		9. Productivity
		10. Quality control

2. State the terms for the following abbreviations related to flexible manufacturing.

a. WIP _____

b. QC _____

c. FMS _____

d. CIM _____

e. JIT _____

f. CNC _____

g. JIC _____

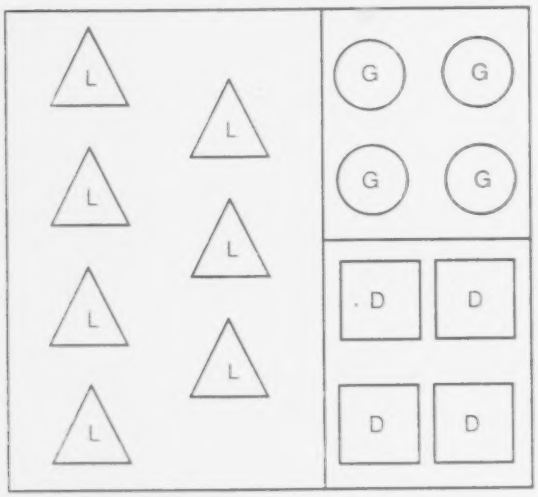
3. Distinguish among the three types of manufacturing by writing the letters which correspond to the types in the blanks provided. Choose from the following: "B" for batch manufacturing, "CO" for continuous manufacturing, and "CU" for custom manufacturing.

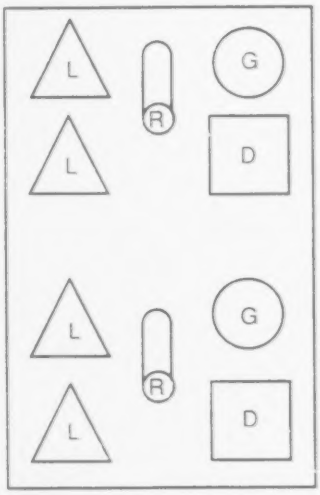
_____a. Manufactures large quantities of products using processes that do not stop at any time. This is commonly done by computer-integrated machines and robots that monitor and perform the manufacturing processes.

_____b. Makes specialized, one-of-a-kind or limited numbers of products. This is typically done by skilled craftsmen, and the cost per item is high.

_____c. Manufactures products in lots or groups. This is usually done when the volume of product needed is too low for continuous manufacturing.

4. Identify the basic types of manufacturing plant layouts.





a. _____ b. _____

Written Test

5. Describe the two basic principles of flexible manufacturing.

   a. _____

   _____

   _____

   _____

   b. _____

   _____

   _____

   _____

6. Select true statements concerning the principles of computer-integrated manufacturing by placing an "X" in the blanks next to the true statements.

   _____a. CIM uses computers to manage all of the technologies needed to operate a manufacturing business.

   _____b. Because of the growth, power, and sophistication of computers, CIM has limited some manufacturers from increasing productivity.

   _____c. CIM provides databases of information such as facts, figures, quotes, prices, and statistics that are available to everyone in the plant or factory.

   _____d. CIM is used to streamline business by integrating internal, external, and technical information.

   _____e. CIM is very inexpensive to implement.

   _____f. CIM cannot be applied to only one section of the process and be effective. It must be applied to all areas of the process.

Written Test

7. Complete statements concerning productivity by writing the correct word(s) in the blanks provided below.

   a. There are four basic factors used in measuring productivity—Land, _____, capital, and entrepreneurship.

   b. Simply, employees get paid because of their _____ to the company.

   c. Tools, robots, and _____ are also measured for their productivity.

   d. By looking at a _____ such as a month or a year, the dollar value of goods or numbers of goods is determined by the produced output.

8. Complete statements concerning cost of quality by circling the correct word(s).

   a. Quality is conformance to requirements set by (customers, employees).

   b. The cost of quality is the (actual cost, overhead cost) that is associated with not meeting the requirements set forth.

   c. Striving to reach (low defect, zero defect) will eliminate the nonconformance cost of quality.

   d. Another category of cost of quality is the conformance cost of quality. This involves such costs as (worker's compensation, training), tool/equipment control, and preventive maintenance.

9. Complete statements concerning management by objectives by writing the correct word(s) in the blanks provided below.

   a. Management by objectives is a technique used to measure the _____ of employees.

   b. The MBO concept allows the individual, in cooperation with _____, to set his or her own measurable goals.

   c. The MBO process focuses on the _____, thus trying to understand the working conditions and delineate the tasks and motions correctly so that productivity can increase.

   d. A vital aspect of the MBO technique is to structure work tasks so that the employee feels as though he or she is making a _____, visible contribution to the entire process.

e. The MBO concept also focuses on _____, measuring, and controlling the human factors in conjunction with the machines.

f. Finally, individual productivity is being replaced in industry by _____ productivity.

10. Select true statements concerning just-in-time by placing an "X" in the blanks next to the true statements.

_____a. Just-in-time is focused around having the part ready and available at the next stage in the process the instant the stage is ready for it.

_____b. Just-in-time increases the amount of inventory to be stored.

_____c. Each part in a just-in-time environment must first pass a quality assurance measure and secondly be delivered in a precise manner.

_____d. In the JIT operation, any delay in delivering the parts from station to station could result in increased productivity.

_____e. The tooling, drilling, machining, transporting, and all other areas of the flexible manufacturing system must be precise in order for JIT to work smoothly.

11. Select true statements concerning material handling by placing an "X" in the blanks next to the true statements.

_____a. Once all stages of the FMS environment have been set up, production flow can begin. Material handling gets the parts to and from the proper machines.

_____b. Versatility and flexibility must be built into the equipment used to move parts from one stage to another within the FMS environment.

_____c. Robots are rarely used to move parts from one stage to another.

_____d. Efficient material handling systems increase the number of times materials have to be moved.

_____e. Accumulators are used for temporary storage during material handling.

_____f. Fixed path material handling equipment include elevators, conveyors, and "pick and place" robots.

_____g. Storage bins are not necessary during the material handling process due to the just-in-time philosophy.

***Permission to duplicate this test is granted.**

Flexible Manufacturing
Unit 6

Unit Evaluation Form

Student Name _____ Unit Rating _____

Assignment Sheet 1—Study the Feasibility of Creating a Flexible Manufacturing System to Produce a Product in Your Robotics Lab Rating _____

Comments: _____

_____

Job Sheet 1—Construct a Flexible Manufacturing System in Your Robotics Lab Rating _____

Comments: _____

_____

Written Test Scores

Pretest _____ Posttest _____ Other _____

Other _____

_____

Teacher Signature _____ Date _____

Student Signature _____ Date _____

*Permission to duplicate this form is granted.

Flexible Manufacturing
Unit 6

Information Sheet

1. Terms and definitions

a. **Accumulators** — Storage bins or devices used to hold designated amounts of parts during the manufacturing process

b. **Automated guided vehicle system (AGVS)** — Unmanned, computer-controlled, preprogrammed vehicles that follow special paths within a manufacturing facility to deliver materials to various work stations

c. **Automation** — The operation of machines and processing equipment without an operator controlling them; usually control is by a computer

d. **Computer numerical control** — The use of a dedicated mini or microcomputer to implement the numerical control function

e. **Flexible manufacturing** — Production with machines capable of making a different product without retooling or any similar changeover

Note: Flexible manufacturing is usually carried out with computer numerical controlled machine tools, robots, and conveyors under control of a central computer.

f. **Machine tool** — A power-driven device that is not hand-held and that is used to cut, form, or shape manufacturing material

Examples: Lathes, milling machines

g. **Manufacturing** — The process of taking raw materials and making them into something with a greater value

h. **Mechanization** — The equipping of industry with machines for production work

i. **Productivity** — The ratio of output produced from a given source compared to a similar ratio from another period

j. **Quality control** — A system which inspects parts during the production process continually ensuring that the parts meet the customers' quality requirements

Information Sheet

2. Abbreviations and terms related to flexible manufacturing

a. CAM — Computer-aided manufacturing

b. CIM — Computer-integrated manufacturing

c. CNC — Computer numerical control

d. FMS — Flexible manufacturing system

e. JIC — Just in case

f. JIT — Just in time

g. MBO — Management by objectives

h. QC — Quality control

i. WIP — Work in process

3. Types of manufacturing

a. **Custom manufacturing** — Makes specialized, one-of-a-kind or limited numbers of products. This is typically done by skilled craftsmen, and the cost per item is high.

Example: Making specialized gauges or custom furniture

b. **Batch manufacturing** — Manufactures products in lots or groups. This is usually done when the volume of product needed is too low for continuous manufacturing.

Example: Assembling subassemblies into final assemblies

c. **Continuous manufacturing** — Manufactures large quantities of products using processes that do not stop at any time (operate continuously). This is commonly done by computer-integrated machines and robots that monitor and perform the manufacturing processes.

Example: Producing chemicals or oils

Information Sheet

4. Basic types of manufacturing plant layouts

a. **Process layout (traditional approach)**

(1) Machines are grouped according to the process they perform.

Example: All lathes in one area, all drills in another.

(2) Commonly used for custom or batch manufacturing.

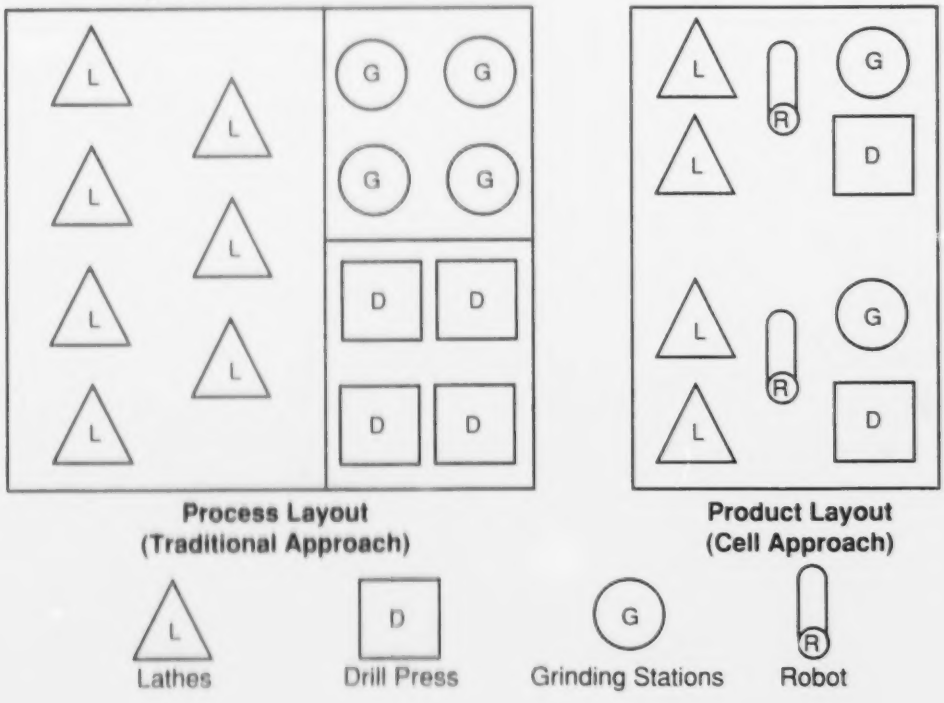
b. **Product layout (cell approach)**

(1) Machines and work stations are arranged according to sequence of operations.

Example: Machine for second operation is next to first machine, or robots are programmed to do several operations at once or in sequence.

(2) Commonly used for continuous manufacturing.

Figure 1



Information Sheet

Note: It is common within the traditional approach that a part spends five percent of its time being machined, five percent of its time for tool change while in the machine tool, and 90 percent of its time waiting to get in the machine tool. A part which should take only a week of manufacturing time ends up taking two months working its way through the process.

The cell approach eliminates the waiting time by doing all operations on the part at the same location. Through the use of the robot, the part can be delivered to the right location at the right time. Each sequence can be programmed in the robot's controller allowing for JIT processing.

5. **Principles of flexible manufacturing**

   a. **Flexibility**

      (1) A flexible manufacturing system (FMS) allows for a variety of products to be produced instead of just one or two.

      (2) Computer numerical controlled machines and robots are commonly used because they are flexible and can be reprogrammed quickly.

   b. **Productivity**

      (1) Automated and computerized machines and robots are used to increase productivity. However they can be very expensive and must pay for themselves through increased productivity.

      (2) All areas of planning and production are analyzed to increase productivity. This includes making both machines and people work smarter and more productively.

      Note: Productivity, quality, and costs are concerns of all types of manufacturing. What distinguishes flexible manufacturing from other types is its improved ability to produce various types of products with only small changes to the equipment.

6. **Principles of computer-integrated manufacturing (CIM)**

   a. Computer-integrated manufacturing (CIM) uses computers to manage all of the technologies needed to operate a manufacturing business.

   b. Because of the growth, power, and sophistication of computers, CIM has become a natural avenue for many manufacturers to increase productivity.

   c. CIM provides databases of information such as facts, figures, quotes, prices, and statistics that are available to everyone in the plant or factory.

Information Sheet

d. CIM is used to streamline business by integrating internal, external, and technical information. Sales figures, purchasing reports, customer and supplier names, engineering designs, and quality control data can be integrated.

e. CIM requires a very high capital expenditure when implemented.

f. CIM cannot be applied to only one section of the process and be effective. It must be applied to all areas of the process.

7. Productivity

a. There are four basic factors used in measuring productivity:

(1) Land

(2) Labor

(3) Capital

(4) Entrepreneurship

Note: Land, labor, and capital show up in ways such as 300 bushels to the acre, 500 parts per shift, or 1500 pieces per hour.

b. Simply, employees get paid because of their worth to the company. Worth is not how many hours they worked or how tired they were at the end of the day but on their contribution to the company's output.

c. Tools, robots, and machinery are also measured for their productivity. How many correct parts versus bad ones did they produce at the end of the production run?

d. By looking at a base period such as a month or a year, the dollar value of goods or numbers of goods is determined by the produced output.

e. Productivity may involve measuring labor productivity, capital productivity, direct cost productivity, or total cost productivity.

Note: Measuring productivity is reasonably simple when dealing with workers or hours as input. However, when dealing with other areas of productivity, measurement becomes more difficult.

Information Sheet

8. Cost of quality

a. Quality is conformance to requirements set by customers (internal or external).

b. The cost of quality is the actual cost that is associated with not meeting the requirements set forth. This is called a nonconformance cost of quality.

Example: We are producing crank shafts for an external customer who has set a specific diameter for those shafts. After production of those shafts, we learn that we are 10 mils oversized. There now becomes some cost associated with the quality of those shafts. The rework time involved in correcting the shafts becomes one of the costs associated with quality.

c. Striving to reach zero defect will eliminate the nonconformance cost of quality. This means that products need to be designed, fabricated, and tested correctly the first time and every time thereafter.

d. Another category of cost of quality is the conformance cost of quality. This involves such costs as training, tool/equipment control, and preventive maintenance.

Note: A typical manufacturing operation will incur approximately one third of its cost in conformance cost.

9. Management by objectives (MBO)

a. Management by objectives is a technique used to measure the performance of employees.

b. The MBO concept allows the individual, in cooperation with management, to set his or her own measurable goals.

Note: Management by objectives is commonly used by self directed work groups which are being used in an increasing number of industries.

c. The MBO process focuses on the worker, thus trying to understand the working conditions and delineate the tasks and motions correctly so that productivity can increase.

d. A vital aspect of the MBO technique is to structure work tasks so that the employee feels as though he or she is making a meaningful, visible contribution to the entire process.

Note: Employees can be motivated if treated correctly and their productivity can reach higher levels. Employees must feel that what they are doing is adding value to the process.

Information Sheet

e. The MBO concept also focuses on designing, measuring, and controlling the human factors in conjunction with the machines.

f. Finally, individual productivity is being replaced in industry by group productivity or teams. Nonproductive people will be eliminated as the group finds the most efficient way to accomplish its task.

10. Just-in-time (JIT) philosophy

a. Just-in-time plays a vital part in flexible manufacturing by providing parts at desired locations and times during production.

b. Just-in-time is focused around having the part ready and available at the next stage in the process the instant the stage is ready for it.

c. Just-in-time reduces the amount of inventory to be stored by producing the product on an "as needed" basis.

d. Each part in a just-in-time environment must first pass a quality assurance measure and secondly be delivered in a precise manner.

e. In the JIT operation, any delay in delivering the parts from station to station could result in shutting the entire process down.

f. The tooling, drilling, machining, transporting, and all other areas of the flexible manufacturing system must be precise in order for JIT to work smoothly.

g. Lead time, process speed, and the number of pieces to the number of stations must be looked at prior to implementing JIT.

Example of lead time: If a bin holds 40 parts and it takes 10 minutes to deburr a seam on each part, then it will take 400 minutes (or lead time) to work through the bin. Thus we have a 40-to-1 ratio of elapsed time to actual work time.

Example of process speed: If a process can cut 40 pieces per hour and is feeding an assembly operation that can handle 5 parts per hour, we have a ratio of 8 to 1. Therefore, the cutter is working only 40 minutes in each hour or is working all the time and is building up inventory.

Example of number of pieces to the number of stations: If we have 150 pieces in the assembly line and 10 people doing the assembly, we have a ratio of 15 to 1. Therefore, we have 140 pieces considered WIP.

Information Sheet

11. Material handling

a. Once all stages of the FMS environment have been set up, production flow can begin. Material handling gets the parts to and from the proper machines.

b. Versatility and flexibility must be built into the equipment used to move parts from one stage to another within the FMS environment.

c. Efficient material-handling systems minimize how often and how far materials are moved.

d. Mechanization is used whenever possible to handle materials. Robots are commonly used.

e. Material handling equipment may use fixed paths or variable paths.

(1) Fixed path equipment include elevators, conveyors, and "pick and place" robots.

(2) Variable path equipment include fork lifts, overhead cranes, and automated guided vehicles (AGV).

f. Quality checks are commonly made during the material handling process. Sensors are used to check parts for location and gauging for correct dimensions.

g. Accumulators are used for temporary storage during material handling. Some stages can make parts faster than others; therefore, there is a need to have temporary storage.

h. Storage is the final need in the material handling process. Bins are provided to store finished products.

Note: Storage for the JIT environment is greatly reduced in comparison to the traditional way in which parts are stored for months.

Flexible Manufacturing
Unit 6

Assignment Sheet 1—Study the Feasibility of Creating a Flexible Manufacturing System to Produce a Product in Your Robotics Lab

Name _____ Overall Rating _____

Evaluation criteria	Rating
Team title appropriate	_____
Mission statement accurate and descriptive	_____
MBOs appropriate for team mission	_____
Implementation plan complete	_____
Team presentation appropriate and high quality	_____

Introduction: Throughout this course you have been working with individual work cells. These individual cells are known as islands of automation. What makes the manufacturing system flexible is the ability to change the product or process with little or no physical adaptations. This is where the use of programmable equipment comes into play. When a system is completely integrated and controlled by a central computer, it is a computer-integrated manufacturing (CIM) system.

The true success of CIM systems is with the people that design, operate, and maintain the systems. American industry over the past few years has come to realize that the Japanese approach to manufacturing is more successful. In this system all of the individuals involved in the manufacturing process are grouped into teams. These teams are responsible for all aspects of the system from transportation of the raw materials to the marketing of the final product. Our focus is on the actual manufacturing process, from design to completion of the product.

Directions: Your instructor will divide the class into several teams or combinations of teams. The objectives for each team should be formulated and a team mission statement should be decided upon. An example of a mission statement for the maintenance team may be:

> "To maintain the production, material handling, and fixturing equipment to the highest levels possible. To improve upon the design and capabilities of each piece of equipment in order to continually improve the process. To maintain accurate records on all equipment and to implement a preventive maintenance program."

Assignment Sheet 1

Your primary objective is to design a flexible manufacturing system to produce a product in your robotics lab. All aspects of the manufacture of this product must be covered. They should include:

1. **Product design**. This should be the first priority. Design a product that can be effectively manufactured in a flexible setting.

2. **Production processes**. What processes are necessary to produce this product? Study the options available to manufacture the product. Design the individual work cells necessary to produce the product.

3. **Material handling**. How will the materials be handled or moved from cell to cell? Design a material handling system that will take the materials from storage to product completion. This usually consists of conveyors, pallets, fixturing, etc.

After you are assigned to a team with one of the aspects above as your team's responsibility, you should:

1. Formulate a mission statement.

2. Create a list of objectives or MBOs.

3. Devise a plan to implement the objectives.

4. Present the team findings to the class.

Note: This should be a formal presentation that includes all team members. You may use any visual aids you deem necessary.

Assignment Sheet 1

Team Name: _____

MISSION STATEMENT

_____

_____

_____

_____

_____

TEAM OBJECTIVES
(MBOs)

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

Assignment Sheet 1

IMPLEMENTATION PLAN

Flexible Manufacturing
Unit 6

Job Sheet 1—Construct a Flexible Manufacturing System in Your Robotics Lab

Name _____ Attempt Number _____

Date _____ Overall Rating _____

Evaluation criteria	Rating
Work cells operate properly and efficiently	_____
Developed flowcharts using proper symbols	_____
Included proper information on all documentation	_____
Preventive maintenance schedule is appropriate	_____
System operates properly and efficiently	_____

A. Tools and materials

Note: These will vary based on the equipment available and the product being produced. The teams should produce their own list of tools and equipment specific to their system.

B. Procedure

Note: Each system will differ depending on the equipment available in your lab and on the product you manufacture.

☐ 1. After reviewing each team presentation and implementation plan, form installation teams to set up each work cell, as well as all fixturing and material handling equipment.

Note: Your instructor will act as project engineer and provide each team with any assistance they may need.

☐ 2. Compile all documentation required such as material and equipment list, flowcharts, programs, and preventive maintenance schedules.

☐ 3. Test your system and debug programs as necessary.

☐ 4. Perform mechanical adjustments as necessary.

☐ 5. Upon completion, have your instructor check your work.

Note: This would be a good time for your class, vocational student organization, or club reporter to write a news release about the class project for your local paper or school newsletter.

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